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MATERIALS COMPATIBILITY STUDIES WITH FUEL/ALCOHOL MIXTURES

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Representative fuel-resistant elastomers, plastics, and metals were evaluated for compatibility with commercial gasolines, diesel fuel, ASTM test fuels, and blends thereof with ethanol and methanol at several concentration levels. The test program was designed to ascertain the effects of the fuels on the materials as well as the effects, if any, of the materials on the fuels. Results were analyzed and interpreted in terms of significant changes in the performance characteristics of the materials and the fuels which would be indicative of potential incompatibilities for use in end items of military equipment.

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PREFACE

The Material Technology Laboratory's technical and laboratory staff performed the work and preparation of this report. Kenneth W. Knutson, Donovan Harris, Thomas Rowe, David Reynolds, Eric Vasey, and Janelle D. Beckstrom performed most of the laboratory testing and sample preparations.

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MATERIALS COMPATIBILITY STUDIES WITH FUEL/ALCOHOL MIXTURES

I. INTRODUCTION

1. Subject. This report details investigations conducted and results obtained in efforts to evaluate the compatibility of materials with petroleum fuel/alcohol mixtures and to determine the effects of these materials on fuels and fuel/alcohol mixtures.

2. Background. Deterioration of elastomeric or plastic end items such as gaskets, diaphragms, "O" rings, hose, tubing, and coated fabrics used in fuel storage tanks is essentially proportional to the aromatic content of petroleum fuel to which the material is periodically or continually exposed. The technology of producing fuels and their ultimate composition is constantly changing. Ecological factors, such as pollution consciousness, and the uncertainties associated with immediate and future availability of military fuel supplies prompted by recent shortages of hydrocarbon fuels have revived an interest in the use of methyl alcohol (methanol) and ethyl alcohol (ethanol) as supplementary automotive fuels. Gasohol, a 90/10 blend of unleaded gasoline/ethanol originally marketed only in the midwest, is now being sold in virtually all states. Gasoline/ethanol blends are currently being used in Brazil, and methanol blends will soon be available in Europe. Alcohol has one overwhelmingly attractive attribute —seemingly an endless supply. Ethanol can be distilled from fermented vegetable and fruit matter, while methanol can be obtained as a by-product from plants, lumbering, manure, and garbage, as well as from coal. Alcohol as a fuel has advantages; i.e., it is clean, energy efficient, and can be made from replaceable materials, but its deleterious effects on metallic and nonmetallic materials needed further investigation. Much has been written on the corrosive action of fuel blends, their water tolerance, their fuel characteristics, and the composition of their emission gases. Concern has been expressed by automotive engineers and fuels-handling parts suppliers about the swelling actions of alcohols on materials (especially rubber parts) causing possible malfunctioning of the fuel-handling system. Recent attention to mixing ethanol and methanol with gasoline to augment fuel supplies has prompted these studies. The objectives of this program were, therefore:

a. To conduct material compatibility studies with fuel/alcohol mixtures.

b. To determine the effects of materials on fuel/alcohol mixtures.

II. INVESTIGATION

3. Scope. Work under this project was divided into three phases. The first phase encompassed the compatibility of rubber materials with various fuels and fuel/alcohol mixtures. The determination of the extent of deterioration in physical properties of rubber materials exposed to gasolines, diesel, standard test fluids to simulate fuels, methanol, ethanol, gasoline/alcohol mixtures, standard test fluid/alcohol mixtures, and diesel/alcohol mixtures was investigated. The second phase concerned similar compatibility studies employing plastic and metallic materials. The third phase investigated the effects of exposure to the various materials on the fuels. Materials, test fluids, and methods used in each phase are detailed as follows:

a. Phase I. Fourteen rubber types (Table 1) which have been used or have potential for use in military vehicle components such as gaskets, seals, hoses, tubing, and diaphragms or in coated fabrics for fuel storage tanks and other components of fuel-handling and distribution systems were used in this investigation. Ten elastomeric compounds representative of rubber types commonly used in fuel resistance applications were selected, mixed, and vulcanized into 6-in. by 6-in. test sheets having a thickness of about 0.080 in. Formulations and curing conditions for these componds are shown in Table 2. Since it was desired to evaluate only the inherent fuel-resistant properties of these rubbers, no effort was made to optimize this characteristic. The other four elastomeric materials were obtained as cured sheets from end item fabricators and the formulations were not revealed. A total of 33 test media were selected. They consisted of standard test fluids representing gasolines of various aromatic content, leaded and unleaded gasolines, diesel, methanol, ethanol, standard test fluid/alcohol mixtures, gasoline/alcohol mixtures, sour gasoline, sour gasoline/alcohol mixtures, and diesel/alcohol mixtures. Both methanol and ethanol were used in mixtures of 5, 10, 20, 50, and 100 percent alcohol by volume. These test fluids, their code identification, and their compositions are shown in Table 3 for further reference. The ethanol used in this study was denatured ethanol; the methanol was Fisher certified ACS grade containing no more than 0.1 percent water. All the test fluids were stored in 5-gal stainless steel safety cans and transferred to brown glass bottles prior to testing and were shaken before each test portion was removed, thus assuring homogeneity.

b. Phase II. This study comprised an evaluation of the effects of 12 fuels on 10 plastic and 7 metallic materials. Most of the selected plastics —both thermosets and thermoplastics—have been described as being resistant to both aliphatic hydrocarbons and alcohols.[1] With the exception of polypropylene, all the plastics tested were rated as exhibiting excellent chemical resistance (showing no discernible attack) or fair chemical resistance (showing mild attack under limited use). The types of plastics chosen for this study were materials being used extensively for corrosion protection in the form of paints, potting compounds, adhesives, coatings, and linings.[2] These organic compounds have versatile formulations which

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1 Harper, Charles A., "Handbook of Plastics and Elastomers," (75).

2 American Society of Metals—Metals Handbook, Vol 10, 8th Ed. "Failure Analysis and Prevention."

Table 1. Rubber Types Used in Fuel Compatibility Study

Material Code	ASTM-D1418 Designation	Elastomer Type	Trade Name	Manufacturer
LS-53	FVMQ	Fluorosilicone Rubber	LS-53	Dow Corning
PNT-34	FZ	Phosphonitrilic Fluoroelastomer	PNF-200	Firestone
VTR-10	FKM	Fluorocarbon, high fluid resistance	Viton VTR-4590	DuPont
M908-B	—	Blend of nitrile and polyvinyl chloride used in fabrication of coated fabric fuel tanks	Proprietary	—
5897-04	NBR/CM	Blend of nitrile and chlorinated polyethylene rubbers used in the fabrication of fuel hoses	Proprietary	—
J-232	EOT	Polysulfide	Thiokol ST	Thiokol
11CR-1	CR	Polychloroprene	Neoprene WRT	DuPont
B-910	FKM	Fluorocarbon	Viton B-910	DuPont
11CSM-2	CSM	Chlorosulfonated Polyethylene	Hypalon 48	DuPont
11NBR-L-2	NBR	Nitrile, Low Acrylonitrile-Butadiene rubber	Paracril 18-80	Uniroyal
11NBR-H-1	NBR	Nitrile, High Acrylonitrile-Butadiene rubber	Hycar 1031	B. F. Goodrich
11ECO-1	ECO	Epichlorohydrin Copolymer	Hydrin 200	B. F. Goodrich
Ether	Eu	Polyether urethane coating compound used in fabricating coated fabric fuel tanks	Proprietary	—
Ester	Au	Polyester urethane coating compound used in fabricating coated fabric fuel tanks	Proprietary	—

Table 2. Formulations for Elastomeric Compounds Prepared In-House

Ingredients	Parts by Weight									
	LS-53	PNT-34	VTR-10	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1
Silastic LS-53	100.	—	—	—	—	—	—	—	—	—
PNF-200	—	100.	—	—	—	—	—	—	—	—
Viton VTR-4590	—	—	100.	—	—	—	—	—	—	—
Thiokol ST	—	—	—	100.	—	—	—	—	—	—
Neoprene WRT	—	—	—	—	100.	—	—	—	—	—
Viton B-910	—	—	—	—	—	100.	—	—	—	—
Hypalon 48	—	—	—	—	—	—	100.	—	—	—
Paracril 18-80	—	—	—	—	—	—	—	100.	—	—
Hycar 1031	—	—	—	—	—	—	—	—	100.	—
Hydrin 200	—	—	—	—	—	—	—	—	—	100.
Zinc Oxide	—	—	—	—	5.	—	—	5.	5.	—
Stearic Acid	—	—	—	1.	.5	—	—	.5	.5	—
Agerite Resin D	—	—	—	—	—	—	—	2.	2.	—
Zinc Stearate	—	—	—	—	—	—	—	—	—	1.
NBC Antioxidant	—	—	—	—	—	—	—	—	—	1.
Maglite D	—	—	—	—	4.	3.	—	—	—	—
Agerite Stalite S	—	—	—	—	1.	—	—	—	—	—
Calcium Hydroxide	—	—	3.	—	—	6.	—	—	—	—
Elastomag	—	6.	—	—	—	—	—	—	—	—
Litharge	—	—	—	—	—	—	25.	—	—	—
SRF, N-765, Black	—	—	—	60.	—	—	25.	—	—	—
MT, N-990, Black	—	—	25.	—	—	30.	—	—	—	—
FEF, N-550, Black	—	33.	—	—	—	—	—	—	—	30.
SRF-LM, N-762, Black	—	—	—	—	50.	—	—	—	—	—
HAF, N-330, Black	—	—	—	—	—	—	—	45.	45.	—
ERD-90	—	—	—	—	—	—	—	—	—	5.6
Warecure C	—	—	—	—	.6	—	—	—	—	1.2
Kenrich BLE	—	—	—	—	2.7	—	—	—	—	—
Santocure NS	—	—	—	—	—	—	—	1.	1.	—
Sulfur	—	—	—	—	—	—	—	2.	2.	—
Methyl Tuads	—	—	—	—	—	—	—	2.	2.	—
Tetrone A	—	—	—	—	—	—	2.	—	—	—
MBTS	—	—	—	—	—	—	.5	—	—	—
Lime	—	—	—	1.	—	—	—	—	—	—
Zinc Peroxide	—	—	—	5.	—	—	—	—	—	—
Luperco CST	1.4	—	—	—	—	—	—	—	—	—
Diak #7	—	—	2.	—	—	—	—	—	—	—
Luperco 101XL	—	—	1.5	—	—	—	—	—	—	—
Vulcup 40KE	—	2.	—	—	—	—	—	—	—	—
TP-95, Plasticizer	—	—	—	10.	—	—	—	—	—	—
Cure Conditions										
Press Cure, Minutes	15	60	10	40	10	8	30	10	10	10
Temp. (°F)	240	320	350	300	340	350	310	340	340	340
Oven Post Cure, h	24	—	24	—	—	24	—	—	—	4
Temp. (°F)	300	—	450	—	—	450	—	—	—	340

Table 3. Fuels Used in Elastomer Compatibility Study

Code Number	Fuel Identification
1	ASTM Reference Fuel B; 70% Iso-Octane/30% Toluene, ASTM D-471
2	ASTM Reference Fuel D; 60% Iso-Octane/40% Toluene
3	ASTM Reference Fuel C; 50% Iso-Octane/50% Toluene
4	Methanol
5	Ethanol
6	90% Reference Fuel D/10% Methanol
7	90% Reference Fuel D/10% Ethanol
8	80% Reference Fuel D/20% Methanol
9	80% Reference Fuel D/20% Ethanol
10	Regular Leaded Gasoline, Texaco (Aromatic content 29.7%)
11	Unleaded Gasoline, Texaco (Aromatic content 32.8%)
12	90% Leaded Gasoline/10% Ethanol
13	90% Unleaded Gasoline/10% Ethanol
14	90% Leaded Gasoline/10% Methanol
15	90% Unleaded Gasoline/10% Methanol
16	80% Leaded Gasoline/20% Ethanol
17	80% Unleaded Gasoline/20% Ethanol
18	80% Leaded Gasoline/20% Methanol
19	80% Unleaded Gasoline/20% Methanol

Table 3. Fuels Used in Elastomer Compatibility Study (Cont'd)

Code Number	Fuel Identification
20	Sour Test Fuel - ASTM Reference Fuel D with t-Butyl Hydroperoxide
21	90% Sour Test Fuel/10% Ethanol
22	80% Reference Fuel D/10% Ethanol/10% Methanol
23	80% Unleaded Gasoline/10% Ethanol/10% Methanol
24	Sour Gasoline - Unleaded gasoline with t-Butyl Hydroperoxide
25	90% Sour Gasoline/10% Ethanol
26	50% Reference Fuel D/50% Ethanol
27	50% Reference Fuel D/50% Methanol
28	50% Unleaded Gasoline/50% Ethanol
29	50% Unleaded Gasoline/50% Methanol
30	Diesel DF-2
31	95% Diesel/5% Ethanol
32	90% Diesel/10% Ethanol
33	80% Diesel/20% Ethanol

facilitate use in protection of metal structures. Tables 4 and 5 describe the plastics and their uses and suppliers. A variety of industrial manufacturing companies supplied samples of injection molded materials from which specimens were machined. The metallic materials selected, with the exception of magnesium in methanol, are known to be resistant to hydrocarbons and anhydrous alcohols[3] and were based on a Union Oil Company report.[4] Those used in the fuel/alcohol immersion tests are given in Table 6. A total of 12 fuels were used to evaluate the plastic and metallic materials. These fuels, along with their code numbers, are presented in Table 7.

c. **Phase III.** This portion of the study was performed in two sections. The first section investigated effects on 12 of the fuels selected from Table 3 when exposed to the 14 elastomers given in Table 1. In the second section, 12 fuels from Table 7 were exposed to 6 plastics and 4 metallic materials from Tables 5 and 6. Exposure materials used in the testing were selected by the Rubber and Coated Fabrics Group and the Plastics, Ceramics, and Metallurgy Group. Fuels were prepared by Rubber and Coated Fabrics Group for the elastomeric exposures and by the Chemistry Research Group for the plastic and metal exposures.

4. **Tests Conducted.** Tests were conducted as follows:

a. **Phase I.** Initial properties of the rubber-tensile strength, elongation, 100 percent and 200 percent modulus, and Shore A hardness were determined according to procedures detailed in ASTM D-412 and ASTM D-2240. Volume change of the rubber materials after immersion for three days at room temperature in the various test fluids was determined according to ASTM D-471. Retention of tensile strength, modulus, and elongation after the 3-day immersion period was ascertained according to FTMS-601, with values obtained based on the swollen cross sectional area per Paragraph 4.8.1 of method 6111.

b. **Phase II.** Initial properties of plastic materials (tensile, rupture, and yield strengths) and specimen configuration were determined according to ASTM D-1708. The crosshead speed for the brittle materials was reduced to facilitate the plotting of a legible load-deflection curve. The fuel-immersion tests on the plastic materials were run for a 28-day period during which three specimens were suspended in sealed test tubes at ambient temperature. The percent change in ultimate tensile strength and rupture strength was calculated and tabulated. The dimensions of the reduced section were measured before and after immersion to allow for the above calculations. The test procedure for determining the volume swell was the same as that employed in Phase I testing of rubber compounds.

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[3] Fabian, Robert J., "Materials in Design Engineering," No. 202, (Jan 63).

[4] Nakaguchi, G. M. and Keller, J. L., "Ethanol Fuel Modification for Highway Vehicle Use," Union Oil Company of CA (Jul 80).

Table 4. Uses For Plastics in Fuel Service

Plastics	Fuel System Component
Nylon 6/12 glass-filled	Fuel feed lines, brake lines, fuel injection system
Acetal	Fan, gas cap, filler neck, roll-over valve, accelerator pump piston
Nylon 6/6	Tubing, reservoirs, emission canister, gas tank bushing, fuel filter
Nylon 6/6 glass-filled	Radiator end tank
HDPE	Fuel filler neck, gas tank
Phenolic	Automatic transmission reactors
PBT	Gas caps

Table 5. Identification of Plastic Materials Used in Fuel Compatibility Study

Supplier	Plastics	Trade Name	Form
Dupont	Acetal	Delrin 500	Injection Molded
Dupont	Nylon 6/6	Zytel 101L	Injection Molded
Dupont	Nylon 6/6 glass-filled	Minlon 70G33L	Injection Molded
Dupont	Polyethylene terephthalate (PET)	Rynite 545	Injection Molded
Dupont	Nylon 6/12 glass-filled	Zytel 77G43	Injection Molded
Amoco	High-density polyethylene (HDPE)	Amoco 240B2	Injection Molded
Amoco	Polypropylene	Amoco 6014	Injection Molded
Celenese	Polybutylene terephthalate (PBT)	Celenex 3300	Injection Molded
GE	Phenolic	Genal 12983E	Injection Molded
Shell	Epoxy	Epon 820	Liquid resin (14% tetraethylene tetramine)

Table 6. Metals Used in Fuel/Alcohol Studies

Metal	Form
Aluminum	Type 6061-Sheet
Brass	Sheet
Magnesium	Ingot
Steel, Carbon	Sheet
Steel, Long Terne Coated	Sheet
Zinc	Ingot
Zinc	Cast Sheet

Table 7. Test Fluids Used in the Metals and Plastics Compatibility Study

Fuel Code No.	Fuel Descriptions
1	ASTM Reference Fuel B, 70% Iso-octane/30% Toluene
2	ASTM Reference Fuel D, 60% Iso-octane/40% Toluene
3	ASTM Reference Fuel C, 50% Iso-octane/50% Toluene
10	Texaco Leaded Regular Gasoline (Aromatic content 29.7%)
12	Texaco Leaded with 10% Ethanol
14	Texaco Leaded with 10% Methanol
16	Texaco Leaded with 20% Ethanol
18	Texaco Leaded with 20% Methanol
30	DF2 Diesel
31	95% Diesel/5% Ethanol
32	90% Diesel/10% Ethanol
33	80% Diesel/20% Ethanol

The metallic specimens were cut to a size about 1 in. by 3 in., soaked in methylene chloride, and dried to remove any residue from the surface. The specimens were placed in 100-ml beakers and the 12 various fuels were added to cover the metal. An aluminum foil-covered rubber stopper was placed in each beaker to prevent fuel evaporation during the 28-day test period. Visual examination was performed to detect any corrosive effects on the metal surface. The magnesium samples were weighed before and after testing to determine the weight loss due to exposure. This was based on previous knowledge of possible drastic changes in magnesium metal.[3]

The metals which were dip-coated in Epon 820 epoxy (curing agent: 14 percent tetraethylene tetramine) included magnesium ingot, aluminum ingot, zinc ingot, carbon steel sheet, and brass sheet. These specimens were treated similarly to the metal samples with respect to immersion testing and inspection.

[3] Fabian, Robert J., "Materials in Design Engineering," No. 202, (Jan 63).

c. **Phase III.** All material samples were prepared for maximum surface area exposure, thereby producing an accelerated (worst-case) test condition.

(1) **Elastomer Sample Preparation.** All samples were reduced to a 200-mesh powder by using a Spex Freezer Mill. Initially, all of the samples were diced into 1/8-in. cubes. The coarsely diced samples (3 to 6 g) were loaded into impacting vials, cooled for 30 min in liquid nitrogen, ground for 2 min, cooled for 5 min, and then ground for a final 2 min. This method, besides being too time intensive, allowed only a 3-g sample per grinding vial and, consequently, made the powdering process inefficient. With the fourth series of exposures, an analytic Wiley Mill, with a 20 mesh screen, was used to prepare the coarse sample. With the exception of the fluorosilicone rubber, this method was used for all elastomer samples.

(2) **Plastic Sample Preparation.** All of the plastic samples were ground using the analytic Wiley Mill with the 20 mesh screen.

(3) **Metal Sample Preparation.** The metal samples were turned into ribbons on a lathe. The turnings were used as the most practical method for exposing the maximum surface area of sample per unit of weight.

(4) **Fuel Sample Preparation.** All of the test fuels used for the elastomers testing phase were provided by the Rubber and Coated Fabrics Group. The first several fuels were stored in 1-gal glass containers. The last six fuels were supplied in 5-gal stainless steel safety cans. The Chemistry Research Group prepared the fuels for the metal and plastics exposures. These were prepared in 5-gal stainless steel safety cans. The material sample-to-fuel weight/volume ratio of 1 percent constituted a single exposure. Each exposure was run in duplicate, using two 16-oz wide-mouthed amber jars. Four grams of sample/400 ml of fuel, were used for each exposure and all test series were performed on the basis of the fuel as opposed to the exposure material.

Each series was exposed for 28 days at room temperture, 77°F ± 3°. Each jar was agitated for 15 seconds once a week. This method reduced agglomeration of the samples reduced any two-phase alcohol/fuel layers, thus presenting a more uniform test exposure condition. However, it was found that the two layers would reform in a few minutes in the 20 percent methanol sample; the elastomers would also settle out quite rapidly to the bottom of the test containers. A uniform test condition was not achieved in the higher test alcohol/fuel samples; a definite alcohol/fuel interface was noticeable.

At the end of the 4-wk test period, the exposure test container was agitated for 30 seconds and the fuel filtered, using Reeve Agnel 802 50-cm folded circles, into an amber narrow-neck storage bottle. These filtered samples were then refrigerated at approximately 40°F until they could be tested according to the following test methods:

(a) Specific gravity as per ASTM D-1298.

(b) Copper Strip Corrosion as per ASTM D-130.

(c) Gum Content as per ASTM D-381.

(d) Oxidation Stability as per ASTM D-525.

(e) Reid Vapor Pressure as per ASTM D-323.

(f) Distillation as per ASTM D-86.

5. Results. Physical properties of all the rubber materials—original and after fluid immersions—are shown in Table 8. The properties for the plastic materials are depicted in Tables 9 through 12. Changes in the weight of the magnesium metal due to exposure to the test fluids are presented in Table 13. Observations from the visual inspection of the epoxy coated metals after exposure are provided in Table 14.

The oxidation stability for all but eight of the exposures met the minimum acceptable 240-min time period. The results from the other eight exposures are given in Table 15. Copper strip corrosion for all exposures fell within the normal acceptable range. Specific gravity, gum content, Reid vapor pressure, and distillation test results are provided in Tables 16 through 32.

III. DISCUSSION

6. Phase I. Data for the fluid compatibility of the 14 different rubbers underscore the wide variation that can be expected. The type of fuel and the additional presence of alcohol in the mixtures are obviously significant factors. Again, it should be emphasized that these data are not necessarily representative of any ultimate or optimum properties attainable, because no attempt was made to impart improved fuel resistance to the compounds.

The two fluorocarbon compounds (VTR-10 and B-910) exhibited the highest overall retention of tensile strength followed by the polysulfide and ECO rubbers (Figure 1). The NBR and urethane compounds and CSM formulation displayed the greatest loss in strength after exposure to Reference Fuel D, methanol, ethanol, leaded and unleaded gasolines, and fuel/alcohol mixtures. With the exceptions of chloroprene (11CR-11), NBR-L, and ether urethane, methanol generally had a more adverse effect on tensile strength than did ethanol. The fuel/alcohol mixtures (codes 6, 7, 13, and 15) generally effected greater tensile losses than did corresponding base fuels or alcohols tested separately. Losses in ultimate elongation usually parallel those for tensile strength, when non-alcohol containing test fluids are employed. Inclusion of the fuel/alcohol mixtures in this study produced data for this property which was in some cases anomalous and, for the most part, difficult to analyze and interpret. Also, compounds such at the NBR-L, since they had low initial elongation (150 percent), did not retain a sufficient percentage after exposure to produce 100 percent or 200 percent modulus values (Table 8).

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids.

Properties	LS-53	PNT-34	VTR-10	M908B	5097-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
Original														
Tensile, lb/in.^{2}	927	1097	2198	1923	1670	748	2820	1680	3942	1775	3102	1963	1962	1827
Elongation, %	260	80	160	663	260	267	306	215	290	150	230	523	547	547
100% Modulus, lb/in.^{2}	243	N/A	1212	237	1047	258	660	790	1478	985	783	315	858	369
200% Modulus, lb/in.^{2}	690	N/A	N/A	378	1558	565	1720	N/A	3122	N/A	2567	725	1028	590
Hardness, Shore A	58	75	85	70	84	65	71	80	83	77	75	66	85	75
After Immersion for 3 Days at Room Temperature in Test Fuel No. 1 (70/30)														
Tensile Retained, %	76	46	93	62	59	73	34	89	31	18	23	54	41	70
Elongation Retained, %	103	71	96	101	70	75	50	95	60	35	13	59	98	93
100% Modulus, %	68	N/A	93	63	67	83	79	91	31	N/A	90	78	79	101
200% Modulus, %	74	N/A	N/A	71	N/A	96	N/A	N/A	N/A	N/A	N/A	89	82	98
Hardness Change, Points	-14	-9	-2	-11	-13	-5	-17	-3	-21	-6	-5	-10	0	-10
Volume Change, %	19.5	23.5	.83	12.1	23.1	5.7	60.7	1.3	46.0	49.5	23.2	26.1	33.0	9.7
After Immersion for 3 Days at Room Temperature in Test Fuel No. 2 (60/40)														
Tensile Retained, %	71	44	88	55	48	68	29	92	19	15	18	50	40	61
Elongation Retained, %	99	75	92	104	58	90	47	100	46	33	39	57	102	91
100% Modulus Retained, %	65	N/A	97	50	58	94	75	93	31	N/A	N/A	82	81	64
200% Modulus Retained, %	75	N/A	N/A	61	N/A	73	N/A	N/A	N/A	N/A	N/A	89	81	74
Hardness Change, Points	-13	-12	-2	-15	-18	-6	-17	-3	-23	-7	-7	-9	0	-12
Volume Change, %	20.2	27.0	1.26	20.6	35.4	8.8	93.1	2.6	61.8	62.1	30.9	33.6	40.2	14.4
After Immersion for 3 Days at Room Temperature in Test Fuel No. 3 (50/50)														
Tensile Retained, %	70	46	90	46	36	52	24	93	21	11	14	42	37	43
Elongation Retained, %	97	75	94	100	49	57	41	99	48	22	33	49	101	88
100% Modulus Retained, %	67	N/A	91	47	52	88	77	92	32	N/A	N/A	78	75	64
200% Modulus Retained, %	75	N/A	N/A	53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	86	75	69
Hardness Change, Points	-12	-13	-2	-17	-20	-9	-19	-4	-28	-7	-6	-12	0	-12
Volume Change, %	20.4	28.5	1.00	30.3	47.2	11.9	109.5	3.2	76.4	70.2	40.1	45.8	48.4	18.2
After Immersion for 3 Days at Room Temperature in Test Fuel No. 4 (METHANOL)														
Tensile Retained, %	54	21	74	69	94	81	86	53	91	32	31	56	20	9
Elongation Retained, %	87	46	89	102	100	82	100	88	93	47	53	66	121	82
100% Modulus Retained, %	57	N/A	86	85	89	97	68	61	84	N/A	95	83	44	16
200% Modulus Retained, %	64	N/A	N/A	82	93	99	84	N/A	92	N/A	N/A	90	40	17
Hardness Change, Points	-15	-11	-2	-3	-4	-5	-1	-12	0	-2	-1	-10	-13	-20
Volume Change, %	11.3	108.4	1.69	-.46	2.3	2.3	4.2	20.9	1.01	10.3	16.8	31.5	41.1	24.9

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PNT-34	VTR-10	M908B	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 5 (ETHANOL)														
Tensile Retained, %	71	41	89	72	95	85	85	93	99	23	42	65	19	14
Elongation Retained, %	107	75	94	101	94	89	98	102	100	47	64	74	112	89
100% Modulus Retained, %	59	N/A	95	87	99	97	73	99	95	N/A	86	84	47	17
200% Modulus Retained, %	68	N/A	N/A	84	98	100	84	N/A	95	N/A	N/A	92	44	21
Hardness Change, Points	-11	-10	-3	-4	-3	-4	-1	0	0	-3	-4	-10	-7	-27
Volume Change, %	4.7	19.1	.64	-1.48	.16	.58	2.3	.79	1.04	13.9	14.9	23.8	47.3	23.8
After Immersion for 3 Days at Room Temperature in Test Fuel No. 6 (90% 60/40 10% METHANOL)														
Tensile Retained, %	47	24	78	31	45	47	29	65	15	10	8.7	29	15	6
Elongation Retained, %	90	54	89	90	58	61	48	95	45	22	25	40	108	66
100% Modulus Retained, %	54	N/A	88	41	57	78	77	72	28	N/A	N/A	71	28	15
200% Modulus Retained, %	57	N/A	N/A	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	76	28	17
Hardness Change, Points	-16	-14	-4	-25	-19	-10	-18	-9	-25	-10	-9	-20	-29	-33
Volume Change, %	27.1	67.3	2.14	45.8	38.3	15.3	80.5	10.8	67.1	83.4	57.4	82.7	117.1	53.7
After Immersion for 3 Days at Room Temperature in Test Fuel No. 7 (90% 60/40 10% ETHANOL)														
Tensile Retained, %	49	27	80	32	45	57	29	75	14	13	12	33	16	7
Elongation Retained, %	87	63	91	91	62	71	48	100	44	31	33	45	110	69
100% Modulus Retained, %	56	N/A	86	34	53	72	72	82	28	N/A	N/A	71	34	16
200% Modulus Retained, %	59	N/A	N/A	41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	76	35	18
Hardness Change, Points	-18	-12	-2	-22	-20	-12	-16	-6	-28	-11	-9	-15	-24	-29
Volume Change, %	24.1	48.3	1.29	36.2	36.5	14.0	85.2	4.9	65.5	76.4	47.8	70.2	101.9	40.2
After Immersion for 3 Days at Room Temperature in Test Fuel No. 8 (80% 60/40 20% METHANOL)														
Tensile Retained, %	45	22	66	25	43	54	33	60	16	13	7.4	28	12	6
Elongation Retained, %	81	50	89	79	62	67	48	92	42	27	26	38	82	67
100% Modulus Retained, %	58	N/A	74	34	59	79	84	67	29	N/A	N/A	74	26	14
200% Modulus Retained, %	58	N/A	N/A	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	30	18
Hardness Change, Points	-20	-11	-5	-24	-20	-12	-16	-11	-23	-10	-8	-17	-25	-30
Volume Change, %	29.2	90.2	2.73	48.4	34.7	14.4	72.5	15.2	60.6	83.0	53.4	90.6	134.8	55.0
After Immersion for 3 Days at Room Temperature in Test Fuel No. 9 (80% 60/40 20% ETHANOL)														
Tensile Retained, %	51	22	83	32	48	54	29	77	18	13	10.5	29	14	6
Elongation Retained, %	87	59	98	91	58	71	44	100	45	29	32	40	97	69
100% Modulus Retained, %	57	N/A	85	34	58	72	78	85	29	N/A	N/A	65	29	18
200% Modulus Retained, %	60	N/A	N/A	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	73	32	18
Hardness Change, Points	-19	-13	-3	-20	-19	-13	-16	-7	-27	-11	-9	-18	-20	-32
Volume Change, %	24.9	58.2	1.18	37.3	31.4	14.4	76.0	5.0	61.3	76.0	48.2	82.6	114.4	47.5

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PNT-34	VTR-10	M9088	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 10 (LEADED GASOLINE)														
Tensile Retained, %	80	57	89	75	66	95	37	102	45	19	53	65	42	92
Elongation Retained, %	96	79	96	98	87	90	62	101	71	40	72	71	102	96
100% Modulus Retained, %	90	N/A	96	92	63	113	68	102	44	N/A	93	96	83	87
200% Modulus Retained, %	88	N/A	N/A	90	67	109	N/A	N/A	N/A	N/A	N/A	100	84	95
Hardness Change, Points	-8	-2	-1	-8	-14	-5	-13	-1	-3	-7	-2	-7	0	-4
Volume Change, %	15.0	16.4	.45	7.8	17.1	2.3	64.0	1.2	26.3	48.5	9.6	17.9	32.2	4.9
After Immersion for 3 Days at Room Temperature in Test Fuel No. 11 (UNLEADED GASOLINE)														
Tensile Retained, %	83	48	87	69	61	95	36	93	26	16	48	63	37	65
Elongation Retained, %	101	79	96	101	77	90	58	96	53	33	65	73	99	90
100% Modulus Retained, %	91	N/A	98	82	64	108	72	102	36	N/A	100	93	72	64
200% Modulus Retained, %	86	N/A	N/A	80	64	110	N/a	N/A	N/A	N/A	N/A	89	75	80
Hardness Change, Points	-9	-4	-2	-10	-14	-6	-15	-4	-20	-7	-3	-8	-2	-3
Volume Change, %	16.6	20.1	1.10	11.7	22.7	2.8	67.9	1.7	39.7	51.1	13.3	22.5	42.3	7.2
After Immersion for 3 Days at Room Temperature in Test Fuel No. 12 (90% LEADED GASOLINE/10% ETHANOL)														
Tensile Retained, %	67	42	70	57	60	87	35	85	30	18	19	49	21	14
Elongation Retained, %	100	71	86	101	77	94	58	94	56	31	43	59	105	84
100% Modulus Retained, %	58	N/A	87	70	65	101	71	92	33	N/A	N/A	77	48	21
200% Modulus Retained, %	71	N/A	N/A	71	64	101	N/A	N/A	N/A	N/A	N/A	83	48	22
Hardness Change, Points	-13	-6	-4	-14	-15	-7	-11	-4	-21	-10	-9	-11	-10	-21
Volume Change, %	18.9	32.6	2.0	18.3	20.5	5.2	59.8	2.9	37.1	58.8	30.8	30.0	73.2	26.7
After Immersion for 3 Days at Room Temperature in Test Fuel No. 13 (90% UNLEADED GASOLINE/10% ETHANOL)														
Tensile Retained, %	69	29	71	54	68	85	32	87	28	16	16	44	21	10
Elongation Retained, %	103	54	86	101	78	89	54	101	53	33	39	53	99	76
100% Modulus Retained, %	59	N/A	90	64	61	93	67	93	30	N/A	N/A	71	46	19
200% Modulus Retained, %	71	N/A	N/A	64	64	95	N/A	N/A	N/A	N/A	N/A	83	46	20
Hardness Change, Points	-14	-8	-4	-16	-16	-8	-13	-5	-21	-8	-8	-10	-13	-24
Volume Change, %	19.9	38.6	1.24	21.6	23.9	6.0	71.6	3.4	44.7	64.7	34.6	44.9	78.2	27.4
After Immersion for 3 Days at Room Temperature in Test Fuel No. 14 (90% LEADED GASOLINE/10% METHANOL)														
Tensile Retained, %	51	29	66	48	58	82	37	66	25	17	17	39	16	6
Elongation Retained, %	83	59	94	100	77	91	60	90	55	33	40	47	94	70
100% Modulus Retained, %	49	N/A	73	53	58	85	65	74	29	N/A	N/A	83	33	19
200% Modulus Retained, %	57	N/A	N/A	56	62	91	N/A	N/A	N/A	N/A	N/A	87	35	19
Hardness Change, Points	-13	-11	-5	-15	-17	-8	-13	-8	-23	-7	-10	-12	-21	-25
Volume Change, %	25.1	72.5	3.23	26.7	23.8	7.0	66.5	9.5	40.5	65.7	43.0	61.8	105.3	42.7

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PNT-34	VTR-10	M900B	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 15 (90% UNLEADED GASOLINE/10% METHANOL)														
Tensile Retained, %	51	29	65	49	58	77	37	68	21	18	12	38	18	5
Elongation Retained, %	92	63	86	99	77	80	59	90	53	31	36	48	98	68
100% Modulus Retained, %	55	N/A	75	52	62	97	68	75	28	N/A	N/A	78	40	19
200% Modulus Retained, %	58	N/A	N/A	57	62	98	N/A	N/A	N/A	N/A	N/A	83	40	18
Hardness Change, Points	-15	-10	-4	-19	-17	-10	-13	-7	-23	-10	-5	-11	-18	-32
Volume Change, %	25.7	74.1	2.1	28.9	26.6	9.2	67.5	8.0	47.9	70.8	43.3	62.1	103.8	40.3
After Immersion for 3 Days at Room Temperature in Test Fuel No. 16 (80% LEADED GASOLINE/20% ETHANOL)														
Tensile Retained, %	59	33	83	55	60	79	43	87	36	15	24	47	22	19
Elongation Retained, %	96	66	89	101	72	79	67	92	64	29	54	55	99	88
100% Modulus Retained, %	56	N/A	92	69	66	103	69	96	33	N/A	77	84	48	19
200% Modulus Retained, %	63	N/A	N/A	67	N/A	101	N/A	N/A	N/A	N/A	N/A	89	47	23
Hardness Change, Points	-15	-14	-3	-15	-13	-7	-11	-5	-23	-9	-7	-11	-12	-24
Volume Change, %	19.2	49.9	1.1	19.7	19.2	6.7	54.2	2.5	37.5	61.3	33.4	41.4	80.8	28.1
After Immersion for 3 Days at Room Temperature in Test Fuel No. 17 (80% UNLEADED GASOLINE/20% ETHANOL)														
Tensile Retained, %	60	30	83	52	60	85	37	83	27	15	16	42	22	18
Elongation Retained, %	92	63	96	103	72	84	57	96	55	29	40	50	88	32
100% Modulus Retained, %	68	N/A	83	56	66	103	68	91	33	N/A	N/A	81	50	21
200% Modulus Retained, %	69	N/A	N/A	60	N/A	104	N/A	N/A	N/A	N/A	N/A	89	53	24
Hardness Change, Points	-15	-8	-2	-14	-15	-9	-14	-4	-23	-9	-9	-11	-10	-24
Volume Change, %	21.7	54.1	1.4	25.2	21.7	7.5	60.1	2.5	44.0	65.8	36.0	46.6	80.6	29.7
After Immersion for 3 Days at Room Temperature in Test Fuel No. 18 (80% LEADED GASOLINE/20% METHANOL)														
Tensile Retained, %	51	21	65	46	58	73	36	63	29	13	12	36	14	5
Elongation Retained, %	88	54	88	98	73	79	56	92	59	27	35	45	90	60
100% Modulus Retained, %	67	N/A	77	63	63	94	70	68	29	N/A	N/A	77	35	18
200% Modulus Retained, %	62	N/A	N/A	62	N/A	96	N/A	N/A	N/A	N/A	N/A	84	37	20
Hardness Change, Points	-17	-11	-4	-16	-17	-10	-13	-9	-20	-9	-11	-11	-23	-28
Volume Change, %	25.0	106.6	2.2	31.4	23.8	9.9	60.8	11.7	41.4	69.3	43.3	68.6	105.4	41.0
After Immersion for 3 Days at Room Temperature in Test Fuel No. 19 (80% UNLEADED GASOLINE/20% METHANOL)														
Tensile Retained, %	52	25	68	47	58	73	32	64	26	12	12	39	15	5
Elongation Retained, %	85	54	88	100	76	75	57	88	55	25	33	47	87	60
100% Modulus Retained, %	68	N/A	80	54	62	92	67	75	33	N/A	N/A	78	34	17
200% Modulus Retained, %	62	N/A	N/A	59	N/A	96	N/A	N/A	N/A	N/A	N/A	85	36	20
Hardness Change, Points	-17	-13	-5	-17	-17	-10	-14	-10	-22	-11	-10	-14	-20	-31
Volume Change, %	26.0	100.1	2.2	31.2	24.1	10.0	65.1	11.1	44.4	71.3	45.4	67.1	105.6	41.0

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PVT-34	VTR-10	M908B	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 20 (Sour Standard Test Fuel)														
Tensile Retained, %	83	38	96	46	23	58	25	82	15	13	15	19	33	41
Elongation Retained, %	104	66	100	101	23	78	50	90	42	29	43	61	79	84
100% Modulus Retained, %	86	N/A	92	66	33	73	70	99	31	N/A	61	24	95	55
200% Modulus Retained, %	82	N/A	N/A	66	N/A	75	N/A	N/A	N/A	N/A	N/A	28	77	59
Hardness Change, Points	-8	-10	-3	-20	-26	-10	-14	-3	-28	-12	-6	-28	-4	-8
Volume Change, %	21.6	28.8	.49	29.8	53.3	13.5	112.2	2.4	82.9	79.6	40.9	48.3	52.1	21.0
After Immersion for 3 Days at Room Temperature in Test Fuel No. 21 (90% Sour Test Fuel/10% ETHANOL)														
Tensile Retained, %	60	26	86	48	53	63	31	75	18	14	14	30	20	6
Elongation Retained, %	93	54	96	100	68	74	54	92	46	27	39	46	89	64
100% Modulus Retained, %	79	N/A	89	55	60	86	67	94	31	N/A	N/A	54	46	19
200% Modulus Retained, %	68	N/A	N/A	58	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69	49	21
Hardness Change, Points	-10	-12	-3	-15	-18	-8	-11	-4	-23	-9	-6	-20	-12	-25
Volume Change, %	22.8	46.9	1.1	27.5	29.7	11.7	66.9	4.4	54.7	66.1	42.4	55.0	79.2	34.3
After Immersion for 3 Days at Room Temperature in Test Fuel No. 22 (80% 60/40 Fuel 10% ETHANOL 10% METHANOL)														
Tensile Retained, %	55	24	78	21	45	51	29	65	16	12	8	24	13	6
Elongation Retained, %	91	50	98	70	62	60	50	93	42	27	30	35	73	64
100% Modulus Retained, %	69	N/A	77	43	54	88	77	83	33	N/A	N/A	66	33	18
200% Modulus Retained, %	65	N/A	N/A	46	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	37	20
Hardness Change, Points	-15	-11	-4	-20	-20	-8	-9	-5	-23	-11	-9	-16	-19	-22
Volume Change, %	26.3	74.3	1.4	55.5	41.2	17.9	80.1	8.4	72.8	93.4	60.8	92.3	124.5	50.1
After Immersion for 3 Days at Room Temperature in Test Fuel No. 23 (80% UNLEADED GASOLINE 10% ETHANOL 10% METHANOL)														
Tensile Retained, %	50	26	82	46	59	79	34	67	25	14	14	39	16	7
Elongation Retained, %	97	59	100	100	73	78	52	84	52	31	38	50	86	69
100% Modulus Retained, %	68	N/A	86	55	62	95	76	82	32	N/A	N/A	70	37	18
200% Modulus Retained, %	64	N/A	N/A	59	N/A	102	N/A	N/A	N/A	N/A	N/A	79	40	21
Hardness Change, Points	-13	-11	-3	-15	-14	-5	-11	-5	-21	-10	-9	-16	-15	-26
Volume Change, %	22.6	73.3	1.0	28.1	23.1	8.9	59.4	.51	44.8	70.3	40.7	54.6	92.8	32.2
After Immersion for 3 Days at Room Temperature in Test Fuel No. 24 (Sour UNLEADED GASOLINE)														
Tensile Retained, %	60	46	100	61	59	92	33	84	28	14	42	36	36	53
Elongation Retained, %	80	88	106	102	73	90	53	90	55	31	65	84	94	88
100% Modulus Retained, %	85	N/A	91	92	64	102	73	99	36	N/A	80	40	72	66
200% Modulus Retained, %	81	N/A	N/A	86	N/A	106	N/A	N/A	N/A	N/A	N/A	44	74	73
Hardness Change, Points	-3	-10	-2	-10	-15	-5	-11	-3	-22	-7	-5	-19	-3	-5
Volume Change, %	16.4	21.9	1.52	11.1	24.7	4.5	72.7	1.9	43.6	51.9	15.0	26.8	41.7	10.0

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PNT-34	VTR-10	M908B	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 25 (Sour UNLEADED GASOLINE/10% ETHANOL)														
Tensile Retained, %	59	38	83	51	60	82	25	65	36	20	25	32	20	8
Elongation Retained, %	96	75	96	104	77	93	53	91	59	43	52	60	93	77
100% Modulus Retained, %	70	N/A	86	55	56	81	57	82	26	N/A	78	44	45	16
200% Modulus Retained, %	66	N/A	N/A	59	64	89	N/A	N/A	N/A	N/A	N/A	51	47	21
Hardness Change, Points	-9	-5	-2	-16	-15	-9	-15	-3	-22	-8	-6	-16	-10	-28
Volume Change, %	20.7	42.1	1.10	24.3	26.0	8.3	72.4	3.1	48.7	66.4	36.9	49.2	92.3	33.8
After Immersion for 3 Days at Room Temperature in Test Fuel No. 26 (50% 60/40 50% ETHANOL)														
Tensile Retained, %	56	28	94	48	66	70	33	76	31	13	13	31	16	5
Elongation Retained, %	90	63	103	98	77	81	62	93	63	35	38	56	85	72
100% Modulus Retained, %	71	N/A	83	60	65	88	59	87	29	N/A	N/A	48	44	16
200% Modulus Retained, %	65	N/A	N/A	62	70	89	N/A	N/A	N/A	N/A	N/A	55	44	20
Hardness Change, Points	-8	-7	-2	-11	-12	-5	-10	-4	-23	-8	-8	-16	-14	-26
Volume Change, %	22.7	88.9	1.61	26.0	15.7	9.4	42.3	5.3	36.7	60.3	40.4	54.7	98.9	36.8
After Immersion for 3 Days at Room Temperature in Test Fuel No. 27 (50% 60/40 50% METHANOL)														
Tensile Retained, %	42	22	72	44	60	68	29	53	26	13	12	33	13	5
Elongation Retained, %	79	50	94	97	77	81	55	85	57	33	36	45	84	69
100% Modulus Retained, %	64	N/A	71	53	60	81	60	61	27	N/A	N/A	66	32	16
200% Modulus Retained, %	N/A	N/A	N/A	55	64	86	N/A	N/A	N/A	N/A	N/A	74	34	18
Hardness Change, Points	-12	-5	-4	-17	-14	-9	-12	-9	-19	-8	-8	-14	-18	-29
Volume Change, %	29.7	114.1	3.40	34.3	22.4	11.4	58.1	18.0	39.9	65.5	48.2	76.9	111.3	45.4
After Immersion for 3 Days at Room Temperature in Test Fuel No. 28 (50% UNLEADED GASOLINE/50% ETHANOL)														
Tensile Retained, %	62	19	84	51	68	83	39	76	40	13	21	42	15	9
Elongation Retained, %	101	38	94	98	90	91	65	86	68	35	46	54	82	80
100% Modulus Retained, %	65	N/A	91	61	67	91	66	86	30	N/A	73	71	40	17
200% Modulus Retained, %	63	N/A	N/A	62	70	93	N/A	N/A	N/A	N/A	N/A	80	42	19
Hardness Change, Points	-13	-9	-2	-10	-11	-7	-10	-3	-17	-7	-7	-11	-14	-25
Volume Change, %	20.2	82.0	1.35	21.4	13.9	7.3	43.1	3.4	27.2	56.9	36.8	52.1	89.7	31.0
After Immersion for 3 Days at Room Temperature in Test Fuel No. 29 (50% UNLEADED GASOLINE/50% METHANOL)														
Tensile Retained, %	51	22	75	45	62	71	32	57	40	17	14	37	14	5
Elongation Retained, %	92	50	94	97	78	80	54	88	72	38	39	48	84	68
100% Modulus Retained, %	64	N/A	74	54	64	88	64	63	27	N/A	N/A	71	31	17
200% Modulus Retained, %	59	N/A	N/A	57	66	92	N/A	N/A	N/A	N/A	N/A	82	33	19
Hardness Change, Points	-13	-8	-5	-16	-13	-6	-12	-11	-23	-8	-9	-13	-24	-26
Volume Change, %	27.4	114.4	2.95	29.0	22.4	9.4	61.0	15.3	35.3	64.0	41.6	64.3	104.7	37.3

Table 8. Physical Properties of Rubber Materials Originally and After Immersion in Test Fluids (Continued).

Properties	LS-53	PNT-31	VTR-10	W908B	5897-04	J-232	11CR-1	B-910	11CSM-2	11NBR-L-2	11NBR-H-1	11ECO-1	Ether	Ester
After Immersion for 3 Days at Room Temperature in Test Fuel No. 30 (DIESEL DF-2)														
Tensile Retained, %	93	79	95	93	70	108	43	96	36	51	89	73	57	81
Elongation Retained, %	115	104	97	108	95	108	63	94	93	70	87	87	106	91
100% Modulus Retained, %	77	N/A	96	95	62	102	73	101	84	N/A	97	95	82	59
200% Modulus Retained, %	82	N/A	N/A	89	69	101	N/A	N/A	91	N/A	101	94	81	83
Hardness Change, Points	-12	-10	-4	-10	-16	-5	-16	-2	-5	-8	0	-7	-2	-10
Volume Change, %	3.5	4.3	-.9	5.1	17.8	0.5	51.8	.97	3.2	21.8	5.6	10.5	20.8	2.49
After Immersion for 3 Days at Room Temperature in Test Fuel No. 31 (95% DIESEL/5% ETHANOL)														
Tensile Retained, %	78	67	98	61	65	88	32	86	86	20	37	55	20	18
Elongation Retained, %	109	100	98	104	88	95	54	99	91	45	62	66	91	91
100% Modulus Retained, %	79	[illegible]	94	62	62	97	57	89	79	N/A	84	81	49	20
200% Modulus Retained, %	75	N/A	N/A	62	66	97	N/A	N/A	87	N/A	N/A	87	51	24
Hardness Change, Points	-3	-3	-1	-15	-14	-6	-10	-3	-3	-8	-5	-8	-10	-30
Volume Change, %	7.1	13.0	.76	18.0	25.1	6.0	59.3	1.95	8.5	49.5	17.9	35.5	58.2	26.6
After Immersion for 3 Days at Room Temperature in Test Fuel No. 32 (90% DIESEL/10% ETHANOL)														
Tensile Retained, %	74	50	96	56	62	90	32	83	85	21	34	45	14	13
Elongation Retained, %	104	88	102	102	78	96	53	100	87	47	61	55	79	98
100% Modulus Retained, %	63	N/A	88	59	62	99	67	90	81	N/A	75	80	38	22
200% Modulus Retained, %	57	N/A	N/A	61	65	100	N/A	N/A	86	N/A	N/A	83	39	20
Hardness Change, Points	-5	-5	-2	-19	-14	-5	-12	-2	-3	-7	-5	-11	-15	-32
Volume Change, %	9.0	27.1	1.10	22.3	25.4	6.9	60.2	1.93	9.1	55.2	24.4	46.8	74.5	33.2
After Immersion for 3 Days at Room Temperature in Test Fuel No. 33 (80% DIESEL/20% ETHANOL)														
Tensile Retained, %	75	32	103	54	50	88	34	75	85	23	35	40	15	11
Elongation Retained, %	105	71	100	103	72	90	57	86	86	49	64	54	85	90
100% Modulus Retained, %	69	N/A	94	58	57	96	65	89	84	N/A	70	72	40	21
200% Modulus Retained, %	70	N/A	N/A	61	54	99	N/A	N/A	88	N/A	N/A	80	42	22
Hardness Change, Points	-5	-8	-2	-15	-16	-4	-9	-2	-4	-7	-5	-11	-14	-33
Volume Change, %	9.3	56.3	1.26	23.9	26.27	6.5	57.3	2.48	8.6	58.0	24.9	47.2	83.8	36.5

Table 9. Original Properties of Plastic Materials

Resin	Tensile Strength (lb/in.^{2})	Rupture Strength (lb/in.^{2})	Yield Strength (lb/in.^{2})
Acetal	10,250	10,250	—
PP	—	3,489	4,527
HDPE	—	29,185	37,897
PBT	8,673	—	—
Nylon 6/12 glass-filled	14,217	11,435	—
PET	12,189	—	—
Nylon 6/6 glass-filled	14,721	13,863	—
Nylon 6/6	9,295	7,397	—
Phenolic	3,778	—	—

Table 10. Change in Volume of Plastic Materials Exposed to Test Fluids

	Change in Volume (%)								
Fuel Code No.	Acetal	Nylon 6/6	Nylon 6/6 Glass Filled	PET	Nylon 6/12 Glass Filled	HDPE	Polypropylene	PBT	Phenolic
1	+4.4	+9.4	+11.2	+5.2	−20.3	+13.2	+14.6	−1.6	+1.0
2	+11.2	+10.9	+11.8	+0.8	+9.6	+13.1	+18.1	−2.9	−0.6
3	+12.2	+11.0	+10.8	+1.3	+11.0	+12.1	+18.7	−2.2	+4.5
10	+12.9	+10.7	+10.3	+1.3	+10.5	+8.1	+19.2	−1.9	+1.9
12	+12.6	+12.9	+12.4	+4.5	+13.3	+14.4	+17.7	−2.6	+0.7
14	+15.8	+14.9	+21.6	−1.9	+20.4	+12.0	+18.0	−1.6	+3.5
16	+12.1	+28.3	+12.3	+1.6	+14.3	+11.8	+16.1	−1.6	+2.9
18	+15.5	+27.1	+22.7	+0.9	+21.3	+12.3	+20.1	−2.2	+2.6
30	+11.0	+15.5	+12.3	+4.6	+11.2	+9.1	+4.5	−2.2	+2.9
31	+12.3	+3.6	+2.5	+0.8	+15.5	+9.3	+4.8	−1.9	+3.3
32	+0.4	+15.5	+15.0	+0.9	+1.3	+8.6	+4.7	−3.2	+2.0
33	+12.2	+14.3	+14.4	+0.8	+15.8	+8.8	+4.5	−2.4	+3.2

Table 11. Tensile Strength Properties of Plastic Materials Exposed to Test Fluids

Fuel Code No.	Ultimate Tensile Strength (% Change)								
	Acetal	Nylon 6/6	Nylon 6/6 Glass Filled	PET	Nylon 6/12 Glass Filled	HDPE*	Polypropylene*	PBT	Phenolic
1	+4	+7	+12	+5	−5	+22	−31	−11	−13
2	−1	+6	+13	+8	−3	+20	−35	−14	+23
3	+1	+6	+13	+4	+5	+23	−35	−14	+42
10	+2	+9	+7	+3	+5	+19	−32	−4	+46
12	−5	--	+10	+8	−6	+17	−33	−14	−18
14	−4	−48	−37	--	−21	+18	−37	+12	+17
16	−1	−2	+13	--	+8	+20	−35	+10	+24
18	−6	−47	−36	+6	−3	+19	−36	−12	+12
30	+2	+1	−17	+7	+2	+13	−16	+10	+1
31	−2	−13	−11	+5	0	+15	−17	+5	+15
32	−2	−14	+5	+1	−11	+13	−17	+9	+28
33	−9	−7	−12	+6	+5	+15	−17	+32	+5

*Actual yield strength.

Table 12. Rupture Strength of Plastic Materials Exposed to Test Fluids

	Rupture Strength (% Change)								
Fuel Code No.	Acetal	Nylon 6/6	Nylon 6/6 Glass Filled	PET	Nylon 6/12 Glass Filled	HDPE	Polypropylene*	PBT*	Phenolic*
1	+4	+12	+20	+5	-2	-8	+19	-11	-13
2	-1	+2	+19	+8	+12	+5	+12	+14	+23
3	-1	+5	+10	+5	+11	-8	+14	-14	+42
10	+1	+3	+9	+3	+12	+3	+25	-4	+46
12	-6	+1	+13	-	+4	+9	+21	-14	-18
14	-4	-25	-23	-	-1	+12	+22	+12	+17
16	-1	+5	+15	-	+14	-8	+23	+10	+24
18	-6	-27	-31	-	+21	-11	+15	-12	+12
30	+2	-2	+23	+5	+9	+4	+7	+10	+1
31	-2	-3	-15	+3	+18	+20	+4	+5	+15
32	-4	-1	+3	-4	-7	+5	+23	+9	+28
33	-13	-	-6	+4	+16	+3	+11	+32	+5

*Also, ultimate tensile strength.

Table 13. Change in Weight of Magnesium Metal Exposed to Test Fluids

Fuel Code No.	Change (%)
1	0
2	0
3	0
10	0
12	0
14	- 9.6
16	- 5.1
18	-20.0
30	0
31	0
32	0
33	0

Table 14. Visual 'nspection of Epoxy Coated Metals Exposed to Test Fluids

Fuel Code No.	Zinc	Magnesium	Aluminum	Brass	Carbon Steel
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
10	0	0	0	0	0
12	0	0	0	2	0
14	1,2	1,2,3	1,2	1,2*	2
16	0	0	0	2	0
18	1,2	1,2,3	2,3	1,2*	2
30	1	1	1	0	0
31	1	1	1	0	0
32	1	1	1	1,2	1
33	0	1	0	1,2	1

* Epoxy absorbed a blue-green color from the metal.

0 No visible change.
1 Epoxy absorbed the color of the sample fuel.
2 Epoxy separated from the metal.
3 Metal corroded.

Table 15. Oxidation Stability of Test Fuels Exposed to Elastomers

	Oxidation Stability, Min					
	LS-53 Fluorosilicone	Viton VTR-10	Ether	J-232 Polysulfide	11EC0-1	Nitrile-PVC M-908
Unleaded and 10% Ethanol	190	210	210	225	227	—
Unleaded C 10% Ethanol and 10% Methanol	225	—	—	—	—	—
Unleaded C 10% Methanol	—	—	—	—	195	215

Table 16. Specific Gravity of Test Fuels Exposed to Metals

Fuel	Specific Gravity				
	6061 Al	Brass	C. Steel	Zinc	Control
Leaded	.733	.733	.734	.733	.733
Unleaded	.740	.747	.741	.741	.739
Methanol	.793	.792	.793	.793	.793
Leaded 10% Methanol	.741	.740	.741	.739	.747
Unleaded 10% Methanol	.747	.748	.746	.744	.744
Leaded 20% Methanol	.737	.737	.737	.737	.736
Unleaded 20%Methanol	.748	.748	.748	.749	.747
Ethanol	.793	.794	.794	.794	.794
Leaded 10% Ethanol	.738	.739	.737	.737	.738
Unleaded 10% Ethanol	.744	.742	.743	.743	.741
Leaded 20% Ethenol	.745	.745	.746	.745	.755
Unleaded 20% Ethanol	.750	.749	.750	.748	.747
Unleaded 10% Methanol 10% Ethanol	.752	.752	.751	.752	.748

Table 17. Specific Gravity of Test Fuels Exposed to Plastics

Fuel	Specific Gravity						
	Nylon 6/6	Nylon 6/12	HDPE	Polypropolene	PBT	Phenolic	Control
Leaded	.733	.735	.733	.734	.733	.734	.733
UnLeaded	.743	.741	.742	.754	.741	.740	.739
Methanol	.785	.794	.794	.794	.793	.793	.793
Leaded 10% Methanol	.742	.739	.740	.755	.737	.772	.747
Unleaded 10%Methanol	.748	.748	.746	.747	.745	.747	.744
Leaded 20% Methanol	.741	.741	.746	.756	.737	.763	.736
Unleaded 20% Methanol	.747	.749	.746	.751	.748	.748	.747
Ethanol	.794	.794	.794	.794	.795	.793	.794
Leaded 10% Ethanol	.740	.738	.738	.738	.738	.737	.738
Unleaded 10% Ethanol	.745	.745	.746	.749	.742	.746	.741
Leaded 20% Ethanol	.763	.756	.756	.777	.743	.755	.755
Unleaded 20% Ethanol	.753	.762	.751	.752	.756	.749	.747
Unleaded 10% Methanol 10% Ethanol	.752	.752	.763	.753	.752	.750	.748

Table 18. Specific Gravity of Test Fuels Exposed to Elastomers

	Specific Gravity														
Fuel	Control	LS-53 Fluorosilicone	PNT-34 Phosphazene	VTR-10 Viton	M-908 Nitrile-PVC	5897-04 Nitrile-CPE	Ether	Ester	11CR-1 Neoprene	11NBR-H-1 High NBR	J232 Polysulfide	11ECO-1	11CSM-2	11NBR-L-2 Low NBR	B-910 Viton
Leaded	.7376	.7413	.7400	.7390	.7413	.7383	.7402	.7374	.7395	.7378	.7398	.7388	.7388	.7376	.7402
Unleaded	.7423	.7421	.7458	–	.7454	.7438	.7445	.7428	.7416	.7458	.7447	.7448	.7446	.7428	.7435
Methanol	.7950	.7948	.7954	.7938	.7966	.7948	.7946	.7956	.7942	.7966	.7946	.7958	.7948	.7954	.7945
Leaded 10% Methanol	.7444	.7423	.7426	.7414	.7439	.7427	.7427	.7426	.7436	.7436	.7445	.7431	.7444	.7435	.7429
Unleaded 10% Methanol	.7467	.7467	.7475	.7475	.7480	.7461	.7485	.7461	.7485	.7467	.7482	.7462	.7491	.7462	.7472
Leaded 20% Methanol	.7507	.7526	.7537	.7523	.7523	.7533	.7557	.7614	.7552	.7617	.7624	.7562	.7517	.7535	.7495
Unleaded 20% Methanol	.7438	.7445	.7494	–	.7435	.7429	.7489	.7439	.7425	.7424	.7410	.7464	.7440	.7419	.7429
Ethanol	.7938	.7957	.7946	.7956	.7940	.7960	.7950	.7956	.7940	.7966	.7954	.7964	.7950	.7960	.7942
Leaded 10% Ethanol	.7418	.7555	.7555	.7565	.7565	.7555	.7555	.7536	.7545	.7555	.7555	.7555	.7565	.7555	.7545
Unleaded 10% Ethanol	.7449	.7468	.7458	.7468	.7477	.7462	.7462	.7467	.7462	.7472	.7462	.7462	.7467	.7472	.7615
Leaded 20% Ethanol	.7479	.7515	.7508	.7514	.7502	.7511	.7490	.7502	.7496	.7521	.7504	.7505	.7496	.7514	.7545
Unleaded 20% Ethanol	.7454	.7484	.7484	–	.7474	.7484	.7450	.7437	.7456	.7474	.7469	.7454	.7464	.7484	.7504
Unleaded 10% Methanol 10% Ethanol	.7533	.7512	.7543	.7549	.7549	.7516	.7504	.7508	.7547	.7560	.7549	.7555	.7546	.7564	.7554

Table 19. Unwashed Gum Content of Test Fuels Exposed to Elastomers

Fuel	Unwashed Gum Content, Mg/100ml														
	Control	LS-53 Fluorosilicone	PNT-34 Phosphazene	VTR-10 Viton	M-908 Nitrile-PVC	5897-04 Nitrile-CPE	Ether	Ester	11CR-1 Neoprene	11NBR-H-1 High NBR	J232 Polysulfide	11ECO-1	11CSM-2	11NBR-L-2 Low NBR	B-910 Viton
Leaded	7.5	36.3	14.6	5.6	19.9	51.3	13.1	30.7	49.4	31.4	65.0	18.9	16.0	35.5	34.1
Unleaded	14.1	17.3	17.2	—	22.0	61.3	14.8	38.2	40.4	40.7	42.9	19.0	18.8	42.4	5.2
Methanol	0.9	3.0	35.9	2.7	14.2	34.8	10.9	40.6	26.2	21.2	14.8	28.6	3.5	13.8	8.8
Leaded 10% Methanol	18.4	15.4	23.9	7.8	32.0	50.1	12.8	32.0	44.1	47.3	51.8	25.6	22.7	48.1	5.4
Unleaded 10% Methanol	13.8	16.1	26.5	6.7	29.4	52.9	10.2	34.1	52.2	46.7	47.1	27.1	26.1	43.5	7.4
Leaded 20% Methanol	3.8	42.6	56.3	13.6	66.9	55.9	30.6	72.9	57.6	54.3	56.6	31.8	27.0	48.7	12.1
Unleaded 20% Methanol	6.8	19.5	54.9	—	46.9	27.9	29.4	56.0	55.9	49.7	51.7	40.1	30.3	57.8	10.9
Ethanol	4.2	5.2	31.6	2.7	52.6	17.8	17.3	39.6	17.4	30.4	41.9	18.1	6.8	5.4	6.3
Leaded 10% Ethanol	13.7	22.6	18.8	4.6	11.1	57.0	18.4	44.6	45.3	36.2	40.6	7.5	25.0	51.3	5.7
Unleaded 10% Ethanol	6.9	16.8	25.7	7.9	28.2	40.3	16.1	43.0	45.7	38.4	43.9	28.1	28.1	48.4	11.3
Leaded 20% Ethanol	5.1	15.0	56.6	9.3	50.7	43.5	23.0	44.4	51.0	35.7	57.7	24.8	30.6	40.3	7.1
Unleaded 20% Ethanol	6.8	22.3	39.8	—	75.2	50.8	27.9	67.4	51.7	50.3	60.4	23.7	26.0	50.6	9.8
Unleaded 10% Methanol 10% Ethanol	14.3	21.4	55.0	19.2	27.6	47.5	22.6	53.1	69.9	56.9	72.3	46.2	35.6	59.6	18.2

Table 20. Unwashed Gum Content of Test Fuels Exposed to Plastics

Fuel	Unwashed Gum Content, Mg/100ml						
	Nylon 6/6	Nylon 6/12	HDPE	Polypropolene	PBT	Phenolic	Control
Leaded	5.7	3.1	3.2	9.6	4.6	0.8	1.1
Unleaded	5.6	4.0	4.3	17.3	6.4	1.3	1.4
Methanol	6.4	10.1	4.1	4.6	2.6	14.7	2.1
Leaded 10% Methanol	6.7	17.4	5.2	19.6	7.7	13.1	2.2
Unleaded 10%Methanol	6.2	6.2	9.7	14.4	5.5	10.5	4.2
Leaded 20% Methanol	11.2	8.3	5.2	18.5	8.6	11.1	5.0
Unleaded 20% Methanol	7.8	9.6	4.6	10.1	8.0	11.8	–
Ethanol	7.2	2.4	3.0	3.7	1.7	1.3	1.7
Leaded 10% Ethanol	6.7	11.0	4.9	8.9	11.1	7.0	6.0
Unleaded 10% Ethanol	0.9	4.8	3.4	12.7	1.3	6.4	1.9
Leaded 20% Ethanol	8.7	14.0	7.3	10.8	10.3	12.1	7.2
Unleaded 20% Ethanol	5.6	8.4	5.6	11.5	3.3	6.0	2.4
Unleaded 10% Methanol 10% Ethanol	9.6	8.6	4.0	9.4	4.7	9.5	3.2

Table 21. Unwashed Gum Content of Test Fuels Exposed to Metals

Fuel	Unwashed Gum Content, Mg/100ml				
	6061 Al	Brass	C. Steel	Zinc	Control
Leaded	4.8	9.5	6.0	5.6	1.1
Unleaded	2.2	9.3	2.8	2.9	1.4
Methanol	2.7	1.9	2.1	2.9	2.1
Leaded 10% Methanol	6.3	15.4	4.4	6.0	2.2
Unleaded 10% Methanol	4.5	14.6	8.0	11.9	4.2
Leaded 20% Methanol	7.2	6.8	6.8	5.8	5.0
Unleaded 20%Methanol	3.7	4.8	4.5	4.4	—
Ethanol	1.0	6.6	6.2	1.6	1.7
Leaded 10% Ethanol	5.8	7.9	4.5	5.3	6.0
Unleaded 10% Ethanol	5.6	19.0	3.7	4.8	1.9
Leaded 20% Ethanol	6.5	6.0	6 0	4.5	7.2
Unleaded 20% Ethanol	4.1	7.7	3.4	3.6	2.4
Unleaded 10% Methanol 10% Ethanol	6.0	10.6	4.0	7.1	3.2

Table 22. Washed Gum Content of Test Fuels Exposed to Elastomers.

Fuel	Washed Gum Content, Mg/100ml														
	Control	LS-53 Fluorosilicone	PNT-34 Phosphazene	VTR-10 Viton	M-908 Nitrile-PVC	5897-04 Nitrile-CPE	Ether	Ester	11CR-1 Neoprene	11NBR-H-1 High NBR	J232 Polysulfide	11ECO-1	11CSM-2	11NBR-L-2 Low NBR	B-910 Viton
Leaded	2.2	4.1	1.9	0.9	1.9	49.5	12.2	29.5	48.0	4.1	4.2	2.5	7.9	6.9	4.5
Unleaded	2.5	7.6	2.9	—	5.0	33.3	4.5	28.5	18.9	22.1	14.0	11.5	16.3	21.9	2.5
Methanol	5.2	1.4	35.2	1.8	7.6	3.9	7.2	38.9	3.4	5.9	9.6	25.0	0.1	8.6	5.3
Leaded 10% Methanol	18.4	15.4	23.9	7.8	32.0	50.1	12.8	32.0	44.1	47.3	51.8	25.6	22.7	48.1	5.4
Unleaded 10% Methanol	9.0	10.1	21.2	4.6	6.7	22.2	3.2	27.1	21.1	11.7	19.5	17.3	19.5	18.6	3.1
Leaded 20% Methanol	3.1	2.7	29.2	2.0	13.5	20.3	20.5	61.8	39.3	20.5	41.3	31.3	26.3	28.1	2.3
Unleaded 20% Methanol	1.6	7.0	23.1	—	8.5	14.2	20.9	51.6	28.6	20.0	26.8	21.9	21.0	26.0	5.9
Ethanol	3.1	3.3	29.2	1.4	2.0	4.5	12.5	34.4	3.2	10.1	8.9	16.4	5.8	2.7	1.8
Leaded 10% Ethanol	4.0	4.3	11.3	1.7	0.6	33.3	12.2	39.3	16.8	15.0	5.3	4.4	23.5	16.2	1.6
Unleaded 10% Ethanol	4.0	9.0	17.8	6.3	30.6	39.5	15.7	36.8	22.8	10.2	8.9	18.9	21.9	33.0	8.0
Leaded 20% Ethanol	2.2	9.7	34.4	4.8	10.6	22.4	15.4	35.0	20.5	15.9	21.0	12.4	24.3	28.7	3.4
Unleaded 20% Ethanol	3.8	5.0	31.5	—	4.7	17.8	14.9	47.2	15.7	12.3	2.0	9.7	21.0	9.2	1.5
Unleaded 10% Methanol 10% Ethanol	13.2	10.3	52.8	16.4	20.3	27.3	20.2	47.3	51.8	27.0	35.9	38.0	30.2	39.8	10.5

Table 23. Washed Gum Content of Test Fuels Exposed to Plastics

Fuel	Washed Gum Content, Mg/100ml						
	Nylon 6/6	Nylon 6/12	HDPE	Polypropolene	PBT	Phenolic	Control
Leaded	3.3	1.6	2.0	5.9	3.4	0.2	0.2
Unleaded	1.7	2.4	2.6	8.0	2.3	0.4	0.6
Methanol	4.8	7.8	2.2	3.0	2.5	11.0	0.9
Leaded 10% Methanol	6.7	17.4	5.2	19.6	7.7	13.1	2.2
Unleaded 10%Methanol	2.8	4.7	4.4	7.9	3.8	8.0	2.5
Leaded 20% Methanol	7.5	2.8	2.2	9.5	5.1	7.1	2.1
Unleaded 20% Methanol	3.4	4.8	0.7	1.8	5.5	5.8	—
Ethanol	6.4	1.2	1.7	2.2	1.1	1.1	0.5
Leaded 10% Ethanol	2.9	7.3	4.4	2.8	9.4	6.0	4.5
Unleaded 10% Ethanol	0.1	2.4	3.3	3.2	1.1	0.4	1.3
Leaded 20% Ethanol	6.0	10.1	4.8	5.7	5.2	7.1	4.3
Unleaded 20% Ethanol	5.6	8.4	5.6	11.5	3.3	6.0	2.4
Unleaded 10% Methanol 10% Ethanol	2.8	4.9	3.1	4.5	1.6	6.2	2.4

Table 24. Washed Gum Content of Test Fuels Exposed to Metals

Fuel	Washed Gum Content, Mg/100 ml				
	6061 Al	Brass	C. Steel	Zinc	Control
Leaded	3.4	7.8	4.1	1.8	0.2
Unleaded	1.3	7.7	1.3	0.8	0.6
Methanol	0.9	1.4	1.2	1.5	0.9
Leaded 10% Methanol	6.3	15.4	4.4	6.0	2.2
Unleaded 10% Methanol	3.2	12.9	4.0	7.2	2.5
Leaded 20% Methanol	3.9	5.1	3.4	3.8	2.1
Unleaded 20%Methanol	2.3	3.0	4.1	3.7	—
Ethanol	—	2.0	3.9	1.3	0.5
Leaded 10% Ethanol	2.1	5.1	3.3	4.0	4.5
Unleaded 10% Ethanol	4.4	14.2	3.5	3.2	1.3
Leaded 20% Ethanol	2.8	3.7	3.5	0.8	4.3
Unleaded 20% Ethanol	4.1	7.7	3.4	3.6	2.4
Unleaded 10% Methanol 10% Ethanol	3.5	4.5	1.3	1.4	2.4

Table 25. Reid Vapor Pressure of Test Fuels Exposed to Elastomers.

Fuel	Reid Vapor Pressure, lb/in.²														
	Control	LS-53 Fluorosilicone	PNT-34 Phosphazene	VTR-10 Viton	M-908 Nitrile-PVC	5097-04 Nitrile-CPE	Ether	Ester	11CR-1 Neoprene	11NBR-H-1 High NBR	J232 Polysulfide	11ECO-1	11CSM-2	11NBR-L-2 Low NBR	B-910 Viton
Leaded	9.47	7.67	8.77	7.8	7.5	8.6	8.87	8.77	8.17	9.47	8.57	8.57	9.58	9.18	8.38
Unleaded	10.42	7.32	9.12	–	10.17	6.92	9.37	9.87	8.87	7.77	8.82	8.16	9.60	8.80	9.70
Methanol	3.79	3.78	4.56	4.06	4.06	1.71	1.16	0.96	4.61	4.06	3.81	1.41	0.91	1.31	4.61
Leaded 10% Methanol	12.37	11.67	12.82	12.02	12.42	12.07	11.87	12.17	11.97	11.52	12.02	12.25	11.85	12.55	12.01
Unleaded 10% Methanol	12.71	13.01	12.61	12.41	12.71	13.22	12.22	12.42	12.62	12.42	11.42	12.22	11.42	12.32	11.62
Leaded 20% Methanol	10.02	9.42	9.37	8.57	7.57	10.42	10.02	9.52	9.22	8.32	6.82	10.27	9.67	9.57	9.99
Unleaded 20% Methanol	12.37	10.37	11.37	–	12.51	11.91	12.71	9.61	9.21	9.81	12.55	9.85	11.55	12.01	11.71
Ethanol	2.11	2.11	0.87	1.62	1.47	2.52	2.12	2.17	2.57	0.42	2.17	1.27	0.82	1.02	2.17
Leaded 10% Ethanol	11.47	6.91	6.36	7.11	8.04	7.36	7.54	7.94	7.27	6.77	7.26	7.26	7.17	7.26	7.11
Unleaded 10% Ethanol	10.87	10.81	10.81	11.21	10.82	10.47	9.92	10.45	10.65	10.95	9.37	9.72	10.87	10.37	9.97
Leaded 20% Ethanol	10.20	10.60	10.10	9.80	10.70	10.00	9.80	10.32	10.72	10.16	9.96	10.41	9.81	9.01	9.52
Unleaded 20% Ethanol	9.72	8.62	10.07	–	9.17	9.87	9.17	10.17	9.67	10.31	9.81	10.00	10.62	9.52	9.22
Unleaded 10% Methanol 10% Ethanol	11.31	11.55	10.85	11.31	10.31	12.11	12.07	11.77	11.47	10.63	9.83	10.28	10.23	9.53	10.73

Table 26. Reid Vapor Pressure of Test Fuels Exposed to Plastics

Fuel	Reid Vapor Pressure, lb/in.[a]						
	Nylon 6/6	Nylon 6/12	HDPE	Polypropolene	PBT	Phenolic	Control
Leaded	9.60	8.75	4.90	7.95	8.45	5.95	8.95
Unleaded	8.30	8.50	9.85	8.70	9.10	7.65	7.90
Methanol	3.64	4.35	4.00	3.90	1.60	2.50	2.75
Leaded 10% Methanol	10.80	10.40	8.30	8.10	10.95	9.50	7.95
Unleaded 10%Methanol	7.50	10.60	8.30	11.40	12.60	6.65	12.60
Leaded 20% Methanol	10.80	8.60	9.10	8.50	9.50	10.10	11.35
Unleaded 20% Methanol	10.05	9.85	10.05	10.55	11.25	10.85	11.35
Ethanol	2.20	1.75	1.85	1.20	1.20	1.90	1.65
Leaded 10% Ethanol	10.00	9.25	9.15	9.85	9.85	9.65	7.85
Unleaded 10% Ethanol	7.95	6.65	7.80	8.30	8.25	8.60	10.40
Leaded 20% Ethanol	4.80	5.05	6.05	3.00	7.50	3.75	6.10
Unleaded 20% Ethanol	9.20	5.90	3.55	9.40	5.85	4.45	7.05
Unleaded 10% Methanol 10% Ethanol	10.95	8.15	9.25	7.95	10.30	9.05	10.00

Table 27. Reid Vapor Pressure of Test Fuels Exposed to Metals

Fuel	Reid Vapor Pressure, lb/in.[a]				
	6061 Al	Brass	C. Steel	Zinc	Control
Leaded	9.55	9.35	6.70	7.60	8.95
Unleaded	8.55	8.85	7.70	8.80	7.90
Methanol	1.50	4.30	1.10	3.65	2.75
Leaded 10% Methanol	8.15	8.95	11.05	8.15	7.95
Unleaded 10% Methanol	9.10	10.50	7.50	8.90	12.60
Leaded 20% Methanol	10.50	11.10	9.40	10.50	11.35
Unleaded 20%Methanol	10.00	10.80	11.50	9.15	11.35
Ethanol	1.75	1.90	1.90	2.30	1.65
Leaded 10% Ethanol	7.50	8.60	9.50	9.10	7.85
Unleaded 10% Ethanol	8.85	7.50	8.90	9.40	10.40
Leaded 20% Ethanol	8.20	9.10	6.05	7.95	6.10
Unleaded 20% Ethanol	10.40	9.80	9.70	9.05	7.05
Unleaded 10% Methanol 10% Ethanol	10.40	8.30	9.20	10.10	10.00

Table 28. Residual Distillation Results of Test Fuels Exposed to Elastomers.

Fuel	Residual Distillation, %														
	Control	LS-53 Fluorosilicone	FNT-34 Phosphazene	VTR-10 Viton	M-908 Nitrile-PVC	5997-04 Nitrile-CPE	Estar	Estr	HCR-1 Neoprene	HNBR-H-1 High NBR	E232 Polysulfide	HECO-1	HCSM-2	HNBR-L-2 Low NBR	B-910 Viton
Leaded	1.0	1.5	1.8	1.2	1.3	1.5	1.2	1.5	1.0	1.5	1.0	2.0	1.6	1.0	1.2
Unleaded	1.2	1.7	1.2	–	1.0	1.7	1.0	1.0	1.4	2.8	1.5	1.1	1.1	2.0	1.0
Methanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leaded 10% Methanol	3.3	1.3	2.5	2.3	1.9	1.5	1.0	2.2	1.2	1.4	1.1	1.2	1.2	1.5	1.9
Unleaded 10% Methanol	1.7	1.1	1.0	1.3	1.7	1.2	1.0	1.0	1.0	1.4	1.4	1.0	2.3	1.4	1.0
Leaded 20% Methanol	2.3	2.7	2.5	3.6	3.1	3.7	1.6	1.1	1.8	1.2	1.0	2.9	1.7	2.4	1.2
Unleaded 20% Methanol	2.2	1.9	1.8	–	2.1	1.3	1.3	1.3	1.0	1.6	1.6	1.3	1.2	1.1	1.4
Ethanol	1.0	0.0	0.5	–	0.3	0.5	0.0	0	0	0.5	0.5	0.5	0.5	0.5	0.5
Leaded 10% Ethanol	2.0	1.0	2.8	2.6	2.4	2.4	2.6	2.2	3.2	2.5	2.0	1.1	3.3	2.1	3.3
Unleaded 10% Ethanol	3.0	1.8	2.1	2.1	2.7	1.1	1.0	0.4	1.5	0.8	1.6	3.5	4.1	1.2	1.5
Leaded 20% Ethanol	1.8	1.6	2.0	1.5	1.3	1.4	1.0	1.6	2.0	1.9	1.9	1.8	1.5	1.4	1.2
Unleaded 20% Ethanol	3.9	2.0	1.2	–	1.6	1.2	1.4	3.0	1.6	2.4	1.2	2.3	2.3	1.7	2.1
Unleaded 10% Methanol 10% Ethanol	1.6	1.2	0.6	1.1	2.0	1.7	2.1	2.0	1.8	2.1	2.4	2.7	2.5	1.5	1.4

Table 29. Residual Distillation Results of Tests Fuels Exposed to Plastics

Fuel	Residual Distillation, %						
	Nylon 6/6	Nylon 6/12	HDPE	Polypropolene	PBT	Phenolic	Control
Leaded	1.8	1.4	1.7	2.0	1.9	1.9	2.4
Unleaded	1.6	1.1	—	—	1.0	1.3	2.0
Methanol	0	0	0	0	0	0	0
Leaded 10% Methanol	1.6	2.8	1.7	2.2	2.5	1.8	2.5
Unleaded 10%Methanol	3.0	2.5	1.4	3.0	1.4	2.8	1.6
Leaded 20% Methanol	2.1	3.1	2.6	1.8	1.6	2.2	2.9
Unleaded 20% Methanol	2.3	2.1	3.2	1.8	1.6	2.1	1.9
Ethanol	0.1	—	—	—	0.5	0.5	1.0
Leaded 10% Ethanol	2.0	2.4	2.6	2.2	1.5	—	2.6
Unleaded 10% Ethanol	2.4	1.9	3.1	1.8	1.9	1.8	2.4
Leaded 20% Ethanol	2.0	2.4	1.8	1.8	1.9	3.2	2.2
Unleaded 20% Ethanol	2.4	3.0	1.8	1.9	1.8	2.2	1.8
Unleaded 10% Methanol 10% Ethanol	3.0	2.1	3.1	2.8	1.8	2.2	2.3

Table 30. Residual Distillation Results of Test Fuels Exposed to Metals

Fuel	Residual Distillation, %				
	6061 Al	Brass	C. Steel	Zinc	Control
Leaded	1.6	1.6	2.0	2.1	2.4
Unleaded	1.3	1.7	1.4	1.1	2.0
Methanol	0	0	0	0	0
Leaded 10% Methanol	1.4	1.4	2.0	1.8	2.5
Unleaded 10% Methanol	2.1	1.2	1.1	1.4	1.6
Leaded 20% Methanol	1.7	2.6	1.1	1.5	2.9
Unleaded 20%Methanol	1.8	2.0	2.0	2.1	1.9
Ethanol	—	—	—	0.5	1.0
Leaded 10% Ethanol	2.6	1.8	1.9	1.3	2.6
Unleaded 10% Ethanol	1.6	2.3	1.5	1.4	2.4
Leaded 20% Ethanol	2.3	1.1	1.1	1.5	2.2
Unleaded 20% Ethanol	1.8	2.4	2.1	2.8	1.8
Unleaded 10% Methanol 10% Ethanol	2.4	2.0	2.3	2.6	2.3

Table 31. Distillation of Test Fuels Exposed to Elastomers

Ethanol								
	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	2.0	1.0	173	174	175	175	176	178
Fluorosilicone, LS-53	2.0	0	172	172	173	173	174	179
Phosphazene, PNT-34	1.5	0.5	171	174	175	176	176	178
Viton, VTR-10	1.0	1.0	173	175	175	176	176	179
Nitrile-PVC, M-908	1.5	0.5	171	175	176	176	176	179
Nitrile-CPE, 5897-04	2.0	0.5	173	175	176	176	176	179
Ether	1.5	0	171	175	175	176	176	179
Ester	1.5	0	173	174	175	176	176	179
Neoprene, 11CR-1	3.0	0	173	174	175	175	176	179
High NBR, 11NBR-H-1	1.5	0.5	173	174	175	175	175	179
J-232, Polysulfide	1.5	0.5	174	174	175	175	176	179
11ECO-1	5.5	0.5	174	175	175	176	176	179
11CSM-2	3.0	0.5	173	174	174	174	175	177
Low NBR, 11NBR-L-2	1.0	0.5	172	173	174	174	175	178
Viton, B-910	2.5	0.5	173	174	174	175	176	178

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Methanol								
	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	0.5	0	149	151	151	151	151	151
Fluorosilicone, LS-53	0	0	150	150	151	151	151	151
Phosphazene, PNT-34	1.0	0	151	151	151	151	151	151
Viton, VTR-10	0	0	151	151	151	151	151	152
Nitrile-PVC, M-908	0.5	0	151	151	151	151	151	152
Nitrile-CPE, 5897-04	1.5	0	150	150	150	150	151	154
Ether	0.5	0	150	150	150	150	150	159
Ester	1.5	0	150	150	150	150	150	151
Neoprene, 11CR-1	1.5	0	151	151	151	151	151	153
High NBR, 11NBR-H-1	2.0	0	150	151	151	151	151	155
J-232, Polysulfide	1.5	0	150	150	151	151	151	152
11ECO-1	1.5	0	150	151	151	151	151	153
11CSM-2	1.5	0	151	151	151	151	151	153
Low NBR, 11NBR-L-2	1.0	0	151	151	151	151	151	155
Viton, B-910	1.5	0	151	151	151	151	151	153

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Leaded

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	7.5	1.0	109	141	162	234	398	422
Fluorosilicone, LS-53	4.5	1.5	105	139	160	234	378	413
Phosphazene, PNT-34	3.2	1.8	108	132	152	225	368	402
Viton, VTR-10	6.8	1.2	96	132	157	232	390	415
Nitrile-PVC, M-908	4.2	1.3	104	136	160	235	377	413
Nitrile-CPE, 5897-04	5.0	1.5	99	125	144	215	376	398
Ether	2.8	2.2	104	144	163	233	363	397
Ester	6.5	1.5	110	149	161	235	390	418
Neoprene, 11CR-1	4.0	1.0	105	127	146	220	370	402
High NBR, 11NBR-H-1	4.0	1.5	104	139	160	232	375	412
J-232, Polysulfide	4.5	1.0	106	140	161	232	372	407
11ECO-1	3.0	2.0	95	134	155	231	368	407
11CSM-2	4.4	1.6	105	130	157	231	374	408
Low NBR, 11NBR-L-2	5.0	1.0	112	142	164	236	382	423
Viton, B-910	5.3	1.2	102	134	155	228	383	408

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Leaded ¢ 10% Ethanol

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	7.0	2.0	105	135	148	237	410	419
Fluorosilicone, LS-53	1.0	1.0	106	140	150	225	350	425
Phosphazene, PNT-34	1.7	2.3	118	138	148	228	360	391
Viton, VTR-10	1.4	2.6	120	142	148	231	361	396
Nitrile-PVC, M-908	1.1	2.9	122	141	149	230	358	390
Nitrile-CPE, 5897-04	2.6	2.4	118	140	150	233	367	398
Ether	1.9	2.6	113	138	148	224	360	379
Ester	1.8	2.2	118	141	150	234	364	396
Neoprene, 11CR-1	1.3	3.2	118	140	148	226	358	382
High NBR, 11NBR-H-1	2.5	2.5	111	140	150	232	365	388
J-232, Polysulfide	2.5	2.0	119	141	149	229	360	391
11ECO-1	0.4	1.1	110	136	152	221	349	413
11CSM-2	0.2	3.3	123	141	150	230	355	394
Low NBR, 11NBR-L-2	2.4	2.1	114	141	150	234	369	399
Viton, B-910	0.7	3.3	117	138	148	224	356	384

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Leaded ₵ 20% Ethanol

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	2.2	1.8	97	126	142	168	342	380
Fluorosilicone, LS-53	2.9	1.6	114	128	143	168	344	381
Phosphazene, PNT-34	2.5	2.0	107	130	144	168	346	377
Viton, VTR-10	3.5	1.5	108	132	145	168	350	379
Nitrile-PVC, M-908	4.7	1.3	112	135	148	169	359	389
Nitrile-CPE, 5897-04	3.6	1.4	105	132	146	168	350	379
Ether	5.0	1.0	111	136	150	171	368	404
Ester	3.4	1.6	97	127	143	167	346	374
Neoprene, 11CR-1	3.0	2.0	107	127	142	167	344	378
High NBR, 11NBR-H-1	1.6	1.9	101	125	141	166	343	382
J-232, Polysulfide	2.1	1.9	107	129	143	167	345	382
11ECO-1	3.2	1.8	105	125	140	166	345	370
11CSM-2	3.0	1.5	107	131	144	168	342	386
Low NBR, 11NBR-L-2	4.6	1.4	114	135	148	169	363	405
Viton, B-910	4.8	1.2	114	134	148	169	358	389

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Leaded ₵ 10% Methanol

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	1.2	3.3	97	118	126	212	352	378
Fluorosilicone, LS-53	4.2	1.3	109	121	130	228	372	413
Phosphazene, PNT-34	1.5	2.5	103	116	128	224	360	393
Viton, VTR-10	2.7	2.3	102	126	144	229	366	399
Nitrile-PVC, M-908	3.6	1.9	104	120	129	225	365	393
Nitrile-CPE, 5897-04	5.5	1.5	99	125	128	224	380	400
Ether	6.0	1.0	106	126	130	234	391	412
Ester	2.8	2.2	98	113	122	190	345	370
Neoprene, 11CR-1	4.8	1.2	100	117	125	225	378	403
High NBR, 11NBR-H-1	4.1	1.4	101	120	120	204	362	383
J-232, Polysulfide	7.9	1.1	105	124	129	233	404	405
11ECO-1	4.8	1.2	103	123	129	232	377	410
11CSM-2	5.3	1.2	106	121	129	225	376	399
Low NBR, 11NBR-L-2	3.5	1.5	106	121	124	223	368	391
Viton, B-910	3.1	1.9	102	120	128	223	364	400

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Leaded ₵ 20% Methanol								
	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	2.7	2.3	109	126	131	216	357	381
Fluorosilicone, LS-53	1.8	2.7	112	125	132	225	359	389
Phosphazene, PNT-34	2.0	2.5	113	126	132	204	353	383
Viton, VTR-10	0.9	3.6	104	125	131	218	350	376
Nitrile-PVC, M-908	1.4	3.1	114	125	132	220	355	382
Nitrile-CPE, 5897-04	1.3	3.7	114	125	131	216	350	375
Ether	3.9	1.6	114	125	131	218	364	394
Ester	4.9	1.1	114	127	135	145*	358	394
Neoprene, 11CR-1	1.7	1.8	104	123	131	211	358	382
High NBR, 11NBR-H-1	4.8	1.2	115	129	136	146*	358	389
J-232, Polysulfide	5.5	1.0	116	129	137	146*	365	392
11ECO-1	0.1	2.9	112	125	133	144*	347	382
11CSM-2	1.8	2.7	111	125	131	222	358	386
Low NBR, 11NBR-L-2	1.6	2.4	109	123	130	207	355	378
Viton, B-910	5.3	1.2	114	129	136	146*	376	397

Note: *Phase separation.

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded								
	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	4.3	1.2	105	138	163	239	369	406
Fluorosilicone, LS-53	2.8	1.7	116	146	168	238	359	393
Phosphazene, PNT-34	3.8	1.2	108	143	165	239	365	397
Viton, VTR-10				NOT RUN				
Nitrile-PVC, M-908	7.0	1.0	110	146	170	247	391	422
Nitrile-CPE, 5897-04	3.3	1.7	110	153	176	246	358	403
Ether	4.5	1.0	105	139	164	240	370	406
Ester	6.0	1.0	106	139	165	241	380	411
Neoprene, 11CR-1	3.6	1.4	103	126	146	226	358	398
High NBR, 11NBR-H-1	0.7	2.8	111	143	166	234	348	383
J-232, Polysulfide	4.0	1.5	105	135	158	234	362	397
11ECO-1	4.9	1.1	101	131	153	232	366	399
11CSM-2	3.9	1.1	108	138	161	237	363	403
Low NBR, 11NBR-L-2	6.0	2.0	109	142	166	242	388	408
Viton, B-910	4.5	1.0	97	135	160	239	364	413

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded ₵ 10% Ethanol	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	3.0	3.0	98	124	136	212	355	376
Fluorosilicone, LS-53	3.2	1.8	105	129	143	226	358	396
Phosphazene, PNT-34	5.9	2.1	101	132	145	234	385	414
Viton, VTR-10	3.4	2.1	108	128	140	204	353	386
Nitrile-PVC, M-908	2.8	2.7	108	135	146	218	354	389
Nitrile-CPE, 5897-04	5.4	1.1	102	131	144	228	363	411
Ether	6.0	1.0	107	132	146	225	378	415
Ester	5.6	0.4	103	134	146	236	389	402
Neoprene, 11CR-1	5.5	1.5	107	131	146	223	369	394
High NBR, 11NBR-H-1	8.2	0.8	103	134	145	232	394	394
J-232, Polysulfide	5.4	1.6	106	131	143	231	371	383
11ECO-1	2.5	3.5	103	131	143	224	348	372
11CSM-2	6.1	4.1	100	128	141	225	361	361
Low NBR, 11NBR-L-2	6.3	1.2	100	127	138	224	368	386
Viton, B-910	4.5	1.5	124	149	157	251	373	404

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded ₵ 20% Ethanol	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	0.1	3.9	111	131	158	169	350	380
Fluorosilicone, LS-53	2.5	2.0	107	131	146	166	356	378
Phosphazene, PNT-34	3.8	1.2	111	134	148	167	363	398
Viton, VTR-10				NOT RUN				
Nitrile-PVC, M-908	3.4	1.6	113	137	149	168	364	401
Nitrile-CPE, 5897-04	4.8	1.2	109	137	149	168	371	409
Ether	3.1	1.4	106	130	142	165	350	380
Ester	1.0	3.0	101	130	144	166	347	382
Neoprene, 11CR-1	2.9	1.6	109	129	142	165	354	394
High NBR, 11NBR-H-1	2.1	2.4	108	132	145	166	353	378
J-232, Polysulfide	5.8	1.2	109	134	148	166	380	401
11ECO-1	2.2	2.3	103	125	139	166	350	378
11CSM-2	2.2	2.3	112	132	145	166	353	384
Low NBR, 11NBR-L-2	2.3	1.7	102	132	146	166	350	386
Viton, B-910	1.9	2.1	115	137	149	168	357	396

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded ¢ 10% Methanol

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	4.3	1.7	101	117	126	214	344	368
Fluorosilicone, LS-53	4.9	1.1	102	121	130	232	360	394
Phosphazene, PNT-34	5.0	1.0	103	119	129	224	364	384
Viton, VTR-10	4.7	1.3	102	118	128	228	357	392
Nitrile-PVC, M-908	3.3	1.7	104	117	125	224	355	381
Nitrile-CPE, 5897-04	6.3	1.2	105	122	131	232	375	396
Ether	5.0	1.0	102	119	129	227	362	390
Ester	7.0	1.1	101	119	129	228	370	388
Neoprene, 11CR-1	7.5	1.0	103	122	131	233	380	399
High NBR, 11NBR-H-1	4.6	1.4	102	119	128	225	354	379
J-232, Polysulfide	4.6	1.4	108	122	131	235	366	404
11ECO-1	6.0	1.0	104	116	127	219	366	387
11CSM-2	2.2	2.3	99	119	128	223	346	374
Low NBR, 11NBR-L-2	4.6	1.4	103	120	129	229	360	390
Viton, B-910	5.5	1.0	108	121	130	231	366	378

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded ¢ 20% Methanol

	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	1.8	2.2	97	116	128	142	350	387
Fluorosilicone, LS-53	1.1	1.9	106	120	130	144	349	388
Phosphazene, PNT-34	2.2	1.8	104	119	129	143	348	376
Viton, VTR-10				NOT RUN				
Nitrile-PVC, M-908	2.9	2.1	103	118	127	144	350	381
Nitrile-CPE, 5897-04	3.7	1.3	100	118	129	144	349	380
Ether	4.2	1.3	106	121	130	144	355	385
Ester	4.7	1.3	108	117	126	144	364	395
Neoprene, 11CR-1	6.5	1.0	104	122	132	152	388	416
High NBR, 11NBR-H-1	1.9	1.6	96	117	127	144	347	394
J-232, Polysulfide	3.4	1.6	103	117	127	150	361	391
11ECO-1	4.7	1.3	109	124	132	222	374	396
11CSM-2	3.8	1.2	101	121	130	144	366	407
Low NBR, 11NBR-L-2	4.4	1.1	105	120	128	142	362	391
Viton, B-910	3.6	1.4	104	119	128	156	363	394

Table 31. Distillation of Test Fuels Exposed to Elastomers (Cont'd)

Unleaded + 10% Ethanol and 10% Methanol	% Loss	% Residue	IBP °F	10% °F	20% °F	50% °F	90% °F	EP °F
Control	3.4	1.6	100	125	136	160	342	372
Fluorosilicone, LS-53	2.3	1.2	107	127	138	162	355	400
Phosphazene, PNT-34	1.9	0.6	96	121	136	160	332	402
Viton, VTR-10	4.4	1.1	110	126	138	163	352	389
Nitrile-PVC, M-908	3.0	2.0	110	127	138	163	350	386
Nitrile-CPE, 5697-04	3.3	1.7	104	123	136	163	346	385
Ether	2.9	2.1	100	121	134	159	344	371
Ester	4.0	2.0	98	124	136	162	357	389
Neoprene, 11CR-1	3.2	1.8	105	127	138	163	351	378
High NBR, 11NBR-H-1	2.9	2.1	106	128	139	164	352	387
J-232, Polysulfide	2.1	2.4	101	123	135	161	344	376
11ECO-1	1.3	2.7	106	123	135	160	337	368
11CSM-2	1.5	2.5	102	125	137	162	340	372
Low NBR, 11NBR-L-2	3.5	1.5	101	124	136	160	344	375
Viton, B-910	3.1	1.4	110	129	140	164	355	397

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics

	Ethanol							
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0.5	1.0	168	174	175	175	176	177
Nylon, 6/6	3.0	0.0	183	190	191	192	192	194
Nylon, 6/12	2.0	0	172	174	175	175	176	177
HDPE	3.0	0	168	175	175	175	176	178
Polypropolene	2.0	0	173	174	175	175	176	178
PBT	1.5	0.5	173	174	174	175	176	178
Phenolic	1.0	0.5	172	173	174	174	175	177
6061 Al	1.5	0	172	172	172	174	174	176
Brass	2.0	0	170	174	174	175	176	178
C. Steel	2.0	0	170	174	174	175	175	178
Zinc	1.0	0.5	171	174	175	175	176	177

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

	Methanol							
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0.	0	150	150	150	150	150	152
Nylon, 6/6	2.0	0	150	167	167	167	168	174
Nylon, 6/12	2.5	0	149	149	150	150	150	151
HDPE	0.5	0	150	150	150	150	150	153
Polypropolene	0.	0	150	150	150	150	151	155
PBT	1.0	0	151	151	151	151	151	152
Phenolic	0.	0	150	150	150	150	150	151
6061 Al	0.	0	150	150	150	150	150	152
Brass	1.0	0	150	150	150	150	150	151
C. Steel	1.0	0	150	150	150	150	150	151
Zinc	1.0	0	150	150	150	150	150	151

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Leaded Gasoline								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	1.6	2.4	100	129	149	217	358	399
Nylon, 6/6	0.2	1.8	108	136	156	218	356	414
Nylon, 6/12	3.6	1.4	94	133	153	215	373	408
HDPE	2.8	1.7	95	133	152	217	369	409
Polypropolene	3.5	2.0	98	115	141	215	369	408
PBT	2.6	1.9	98	127	145	213	369	401
Phenolic	2.6	1.9	99	129	150	216	367	406
6061 Al	3.4	1.6	93	130	150	218	373	413
Brass	2.4	1.6	103	135	153	215	366	405
C. Steel	5.0	2.0	91	131	155	225	393	414
Zinc	1.4	2.1	87	130	147	223	355	396

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Leaded 10% Ethanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0.4	2.6	97	128	139	198	339	380
Nylon, 6/6	3.0	2.0	112	140	152	214	380	407
Nylon, 6/12	2.6	2.4	102	128	138	202	355	382
HDPE	0.9	2.6	120	142	152	204	350	375
Polypropolene	3.8	2.2	128	146	157	228	374	402
PBT	3.5	1.5	101	124	135	198	364	396
Phenolic				NOT RUN				
6061 Al	2.4	2.6	102	125	134	193	350	385
Brass	3.2	1.8	98	124	137	199	359	391
C. Steel	2.1	1.9	102	128	137	198	349	384
Zinc	1.7	1.3	107	127	136	199	355	406

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Leaded 20% Ethanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	2.3	2.2	120	152	163	182	369	398
Nylon, 6/6	0	2.0	124	158	166	181	350	403
Nylon, 6/12	1.6	2.4	121	154	162	180	350	404
HDPE	1.7	1.8	121	151	162	180	353	399
Polypropolene	0.7	1.8	120	152	163	180	350	404
PBT	1.1	1.9	110	141	152	180	360	408
Phenolic	0.8	3.2	116	154	163	180	348	371
6061 Al	1.2	2.3	114	143	155	180	355	397
Brass	3.9	1.1	116	149	161	182	376	426
C. Steel	3.9	1.1	121	152	163	183	383	429
Zinc	5.0	1.5	125	150	161	183	397	432

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Leaded 10% Methanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0	2.5	116	125	128	218	346	396
Nylon, 6/6	1.4	1.6	120	136	143	210	358	412
Nylon, 6/12	1.2	2.8	112	134	142	218	357	382
HDPE	1.8	1.7	112	134	142	217	371	417
Polypropolene	2.3	2.2	131	146	148	236	373	400
PBT	0.5	2.5	105	119	124	203	353	391
Phenolic	4.2	1.8	125	144	175	250	394	424
6061 Al	2.6	1.4	96	114	121	195	363	396
Brass	3.1	1.4	99	116	126	200	361	401
C. Steel	3.5	2.0	105	110	120	200	368	391
Zinc	2.7	1.8	98	118	126	213	362	393

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Leaded 20% Methanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0.6	2.9	115	136	145	162	348	394
Nylon, 6/6	2.9	2.1	110	131	138	216	380	410
Nylon, 6/12	1.4	3.1	116	131	137	202	358	391
HDPE	0.9	2.6	118	132	138	218	350	382
Polypropolene	0.7	1.8	122	138	147	163	374	391
PBT	2.4	1.6	119	138	146	202	378	414
Phenolic	0.8	2.2	120	138	148	164	338	378
6061 Al	2.3	1.7	113	134	141	233	377	422
Brass	1.9	2.6	121	135	142	230	377	416
C. Steel	3.9	1.1	116	135	143	230	391	424
Zinc	3.0	1.5	116	131	139	220	375	408

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded Gasoline								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	2.5	2.0	96	133	155	231	361	395
Nylon, 6/6	2.4	1.6	108	141	168	242	373	418
Nylon, 6/12	1.9	1.1	98	128	154	231	349	415
HDPE				NOT RUN				
Polypropolene				NOT RUN				
PBT	2.0	1.0	100	133	157	231	351	413
Phenolic	2.7	1.3	95	135	157	230	360	406
6061 Al	4.2	1.3	95	132	156	234	366	407
Brass	4.8	1.7	99	135	158	235	370	392
C. Steel	0.6	1.4	95	128	153	227	338	402
Zinc	5.4	1.1	97	133	156	234	373	398

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded 10% Ethanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	0.6	2.4	101	124	135	203	345	369
Nylon, 6/6	3.6	2.4	116	143	157	224	378	411
Nylon, 6/12	2.1	1.9	124	146	159	230	361	386
HDPE	0.9	3.1	116	142	154	215	350	380
Polypropolene	2.7	1.8	122	150	162	236	370	396
PBT	2.1	1.9	102	128	140	213	344	390
Phenolic	1.7	1.8	111	143	156	216	347	370
6061 Al	1.9	1.6	96	125	139	216	348	389
Brass	0.7	2.3	103	128	141	211	341	384
C. Steel	3.0	1.5	105	129	141	220	357	392
Zinc	4.6	1.4	105	128	142	221	371	398

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded 20% Ethanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	3.2	1.8	120	147	159	184	368	405
Nylon, 6/6	2.6	2.4	101	143	158	180	351	375
Nylon, 6/12	0.0	3.0	120	152	165	183	349	382
HDPE	1.7	1.8	112	142	156	180	348	390
Polypropolene	1.6	1.9	93	142	156	180	336	391
PBT	1.2	1.8	126	156	166	188	362	402
Phenolic	1.3	2.2	105	143	157	181	346	394
6061 Al	3.2	1.8	123	149	162	186	372	415
Brass	1.6	2.4	113	144	157	182	360	390
C. Steel	0.9	2.1	116	149	161	183	353	396
Zinc	3.2	2.8	111	148	160	187	389	406

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded 10% Methanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	4.4	1.6	100	116	128	216	356	388
Nylon, 6/6	1.5	3.0	106	130	141	222	350	378
Nylon, 6/12	1.5	2.5	116	128	139	212	345	386
HDPE	0.6	1.4	122	142	148	232	350	398
Polypropolene	1.0	3.0	100	121	142	223	345	3[illegible]9
PBT	0.4	4.1	90	114	124	216	336	361
Phenolic	0.2	2.8	110	130	140	220	345	372
6061 Al	1.9	2.1	100	118	127	213	345	375
Brass	5.3	1.2	120	144	153	252	383	416
C. Steel	1.9	1.1	102	112	122	232	360	391
Zinc	2.6	1.4	115	133	144	234	370	408

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded 20% Methanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	2.1	1.9	112	139	150	163	350	376
Nylon, 6/6	1.7	2.3	113	135	144	213	350	374
Nylon, 6/12	1.9	2.1	112	133	143	223	352	383
HDPE	0.8	3.2	123	136	144	232	356	380
Polypropolene	2.2	1.8	119	138	146	161	350	391
PBT	3.4	1.6	112	140	149	162	365	389
Phenolic	2.4	2.1	118	136	145	160	350	386
6061 Al	4.2	1.8	116	141	150	208	398	410
Brass	3.5	2.0	118	140	149	164	364	394
C. Steel	2.0	2.0	114	131	144	161	349	388
Zinc	0.9	2.1	114	135	144	160	340	380

Table 32. Distillation of Test Fuels Exposed to Metals and Plastics (Cont'd)

Unleaded 10% Ethanol and 10% Methanol								
	Loss	Residue	IBP	10%	20%	50%	90%	EP
Control	1.7	2.3	116	139	150	175	358	396
Nylon, 6/6	1.0	3.0	126	138	149	172	346	369
Nylon, 6/12	1.9	2.1	121	140	150	183	351	382
HDPE	0.9	3.1	121	142	152	174	342	365
Polypropolene	0.2	2.8	116	141	152	174	346	378
PBT	2.2	1.8	119	140	151	176	360	390
Phenolic	2.8	2.2	121	142	153	176	364	403
6061 Al	2.6	2.4	121	142	153	175	372	402
Brass	4.0	2.0	114	143	153	178	376	403
C. Steel	1.7	2.3	118	144	154	177	360	398
Zinc	1.9	2.6	123	144	154	177	356	386

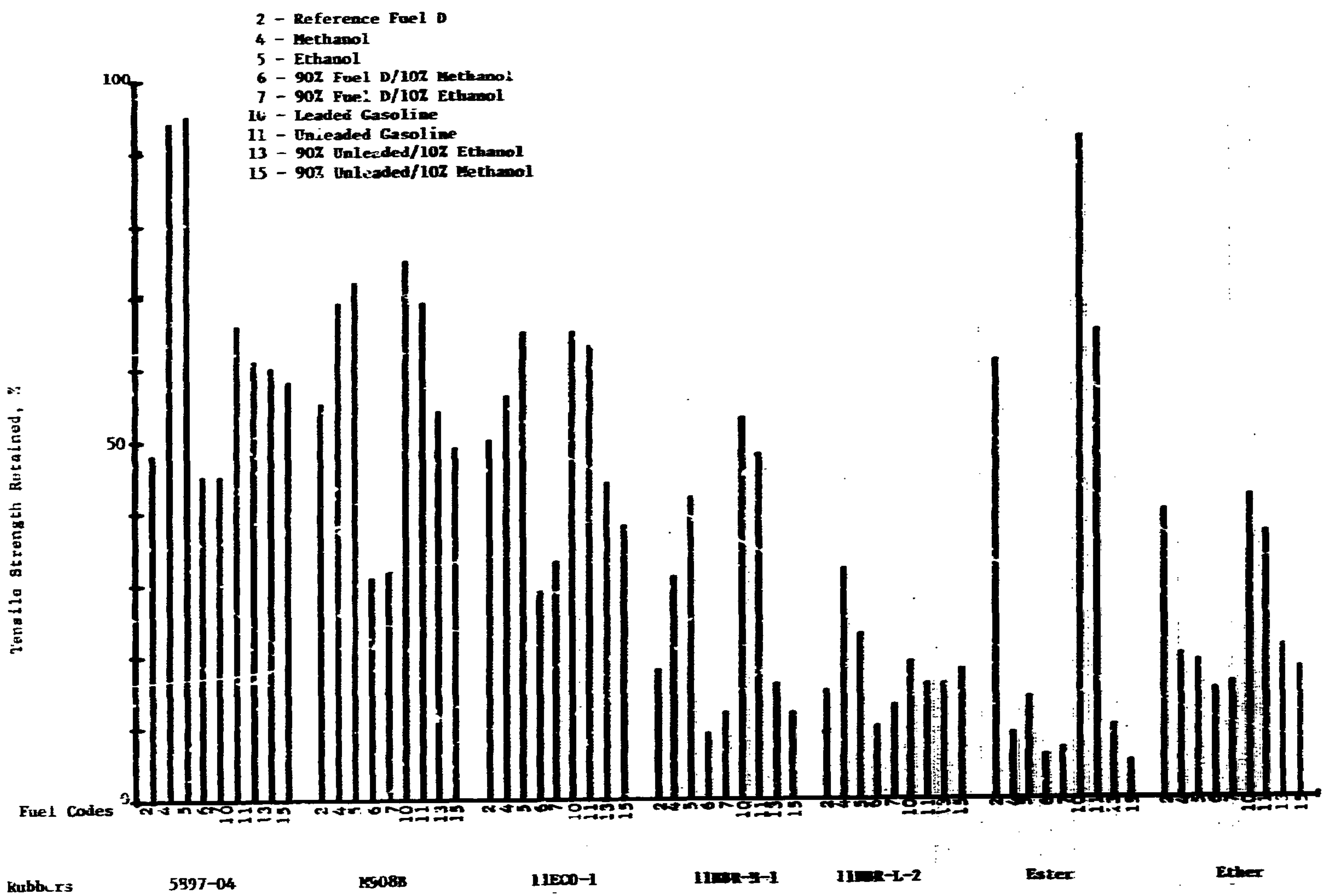

Figure 1. Tensile strength properties of rubber materials after fuel exposure.

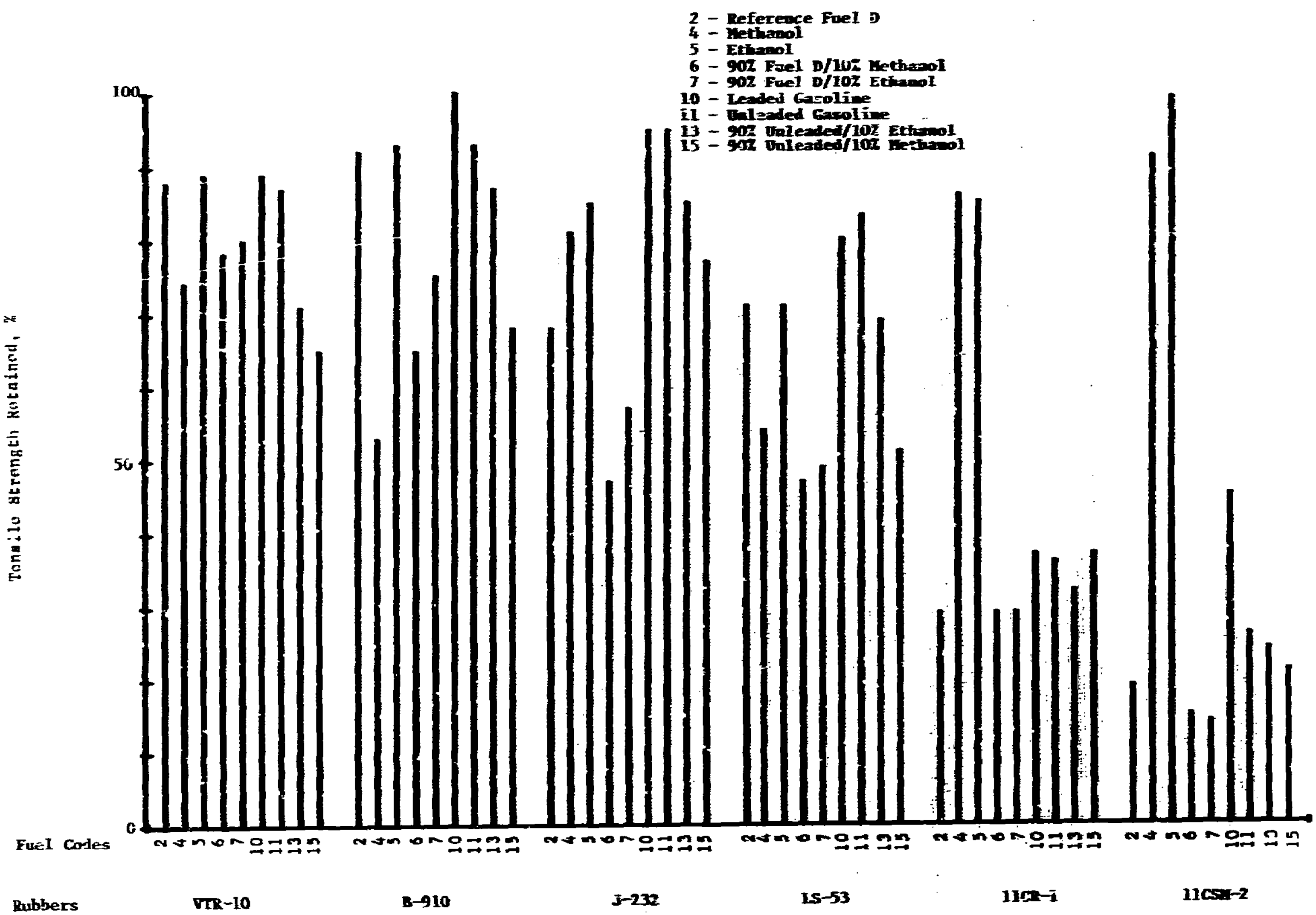

Figure 1. Tensile strength properties of rubber materials after fuel exposure (continued).

Highest retention of modulus after fluid exposure was demonstrated by the VTR-10 compound, followed closely by B-910, J-232, and ECO (see Figure 2). Lowest modulus retention values were displayed by the two NBR's, CSM, and the two polyurethane compounds. Modulus of the NBR-H compound when exposed to alcohols only remained relatively unaffected, but exposure to the fuel/alcohol mixtures produced the greatest loss in modulus of all compounds. Retention of this property was significantly lower for the urethane coating compounds after immersion in either of the alcohols or any of the fuel/alcohol mixtures. As would be expected, those compounds demonstrating highest tensile and modulus retention displayed the least amount of swelling and change in hardness after exposure. The fluorocarbons, fluorosilicone (LS-53), and J-232 were obviously superior in resistance to deterioration than were the other materials, as is shown in Figure 3. Alcohol had little effect on the volume change and hardness properties of the fluorocarbons, chloroprene, polysulfide, 5897-04, M-90-B, and CSM compounds. In most cases, fuel/alcohol mixtures effected more significant changes than fuels or alcohols considered separately.

In Figures 4 through 6, the effects of alcohol content in blended fuels on physical properties of the rubber compounds is depicted. Losses in tensile strength and 100 percent modulus, volume change, and hardness change observed for mixtures containing 10, 20, and 50 percent ethanol or methanol are compared graphically with similar results obtained using a pure unleaded gasoline. The most consistent pattern evolving from examination of Figures 4 through 6 was the obviously greater deleterious effect of substituting methanol rather than ethanol in the resulting mixture. Only the fluorocarbon compound (B-910) evidenced a continual, proportionate degradation in properties as the alcohol content was increased. With the exception of the hose compound (5897-04), the remaining compounds displayed more significant property changes upon the addition of only 10 percent ethanol or methanol. Further fuel dilution with alcohol produced less significant effects. In this respect, the NBR-H and ester urethane were most severely effected. Although not shown, the other fluorocarbon compound (VTR-10) also exhibited excellent resistance to the effects of alcohol blends, and like B-910 and J-232, it had also shown superior performance in the pure unleaded fuel. Other compounds tested but not shown—PNT-34, NBR-L, and ether urethane—performed poorly in the base fuel and in the alcohol blends. Gasohol resistance of the ECO, M90-B, and 5897-04 compounds can be categorized as intermediate with the likelihood that proper compound modifications could effect improvement.

An additional alcohol blend used in this study—Fuel No. 23 of Table 8—contained both methanol and ethanol, each at the 10 percent level in 80 percent unleaded gasoline. Changes in properties of compounds exposed in this medium closely paralleled those observed for Fuel No. 19 which was a blend of 20 percent methanol and 80 percent unleaded gasoline.

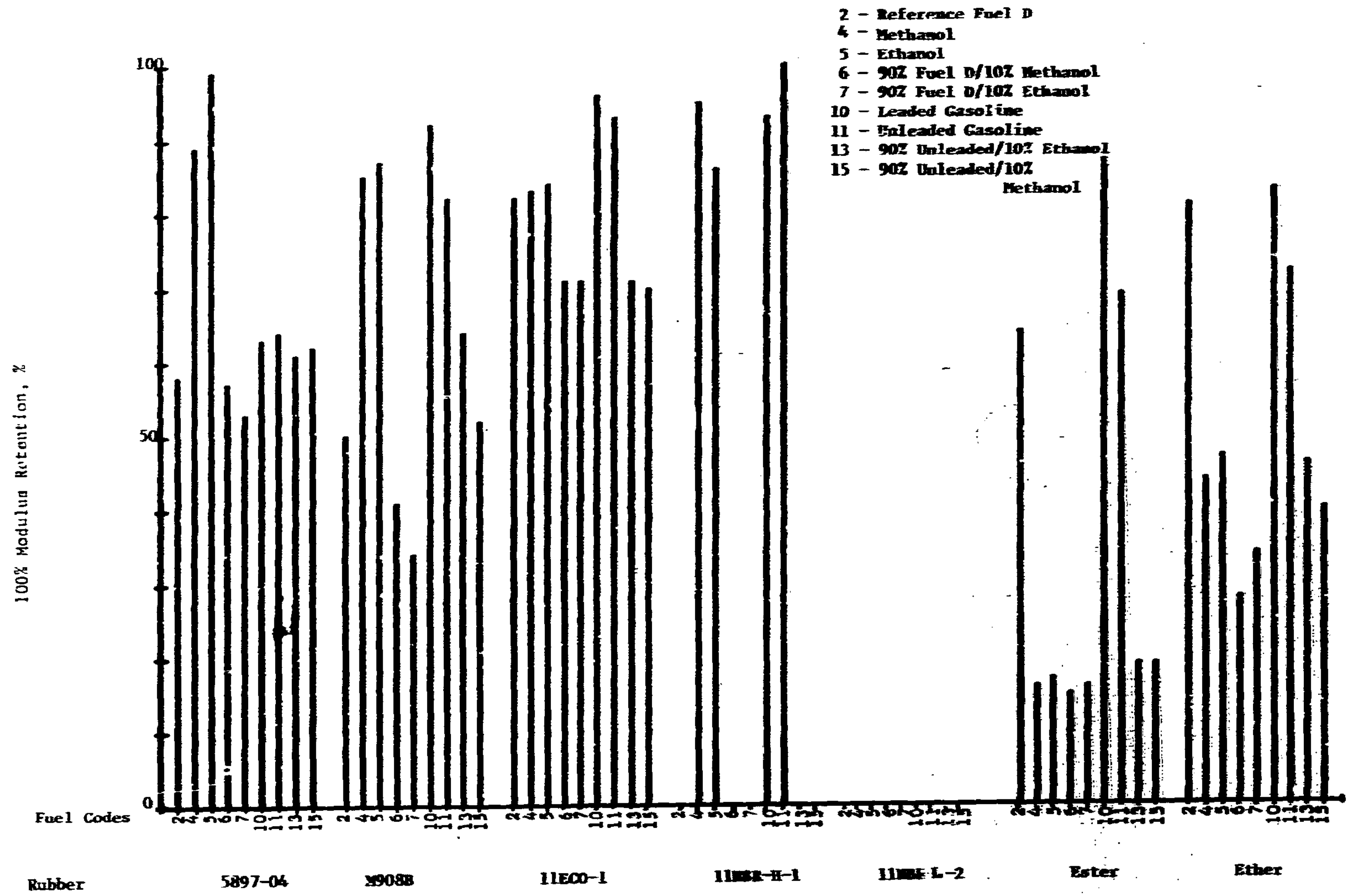

Figure 2. Modulus properties of rubber materials after fuel exposure.

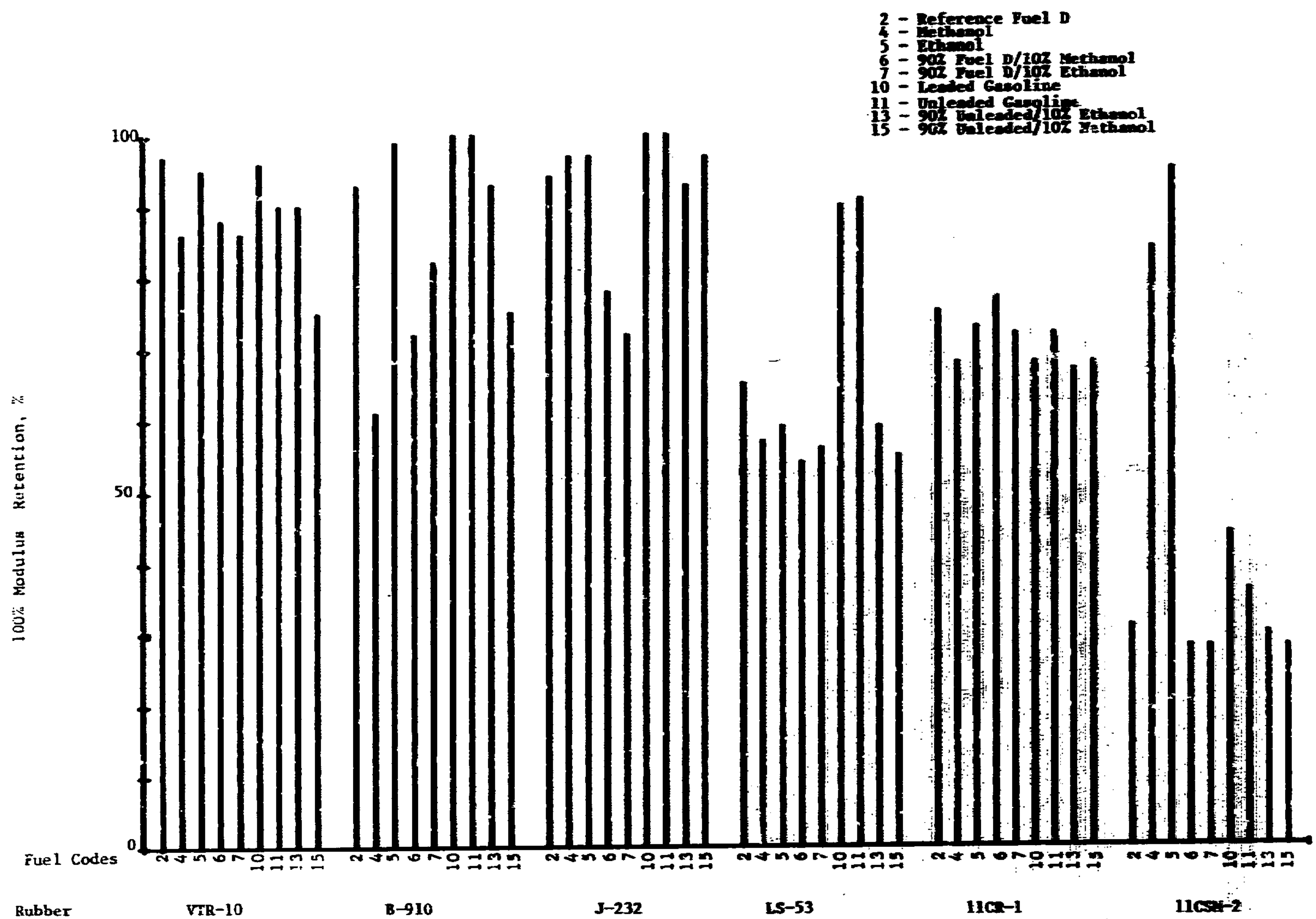

Figure 2. Modulus properties of rubber materials after fuel exposure (continued).

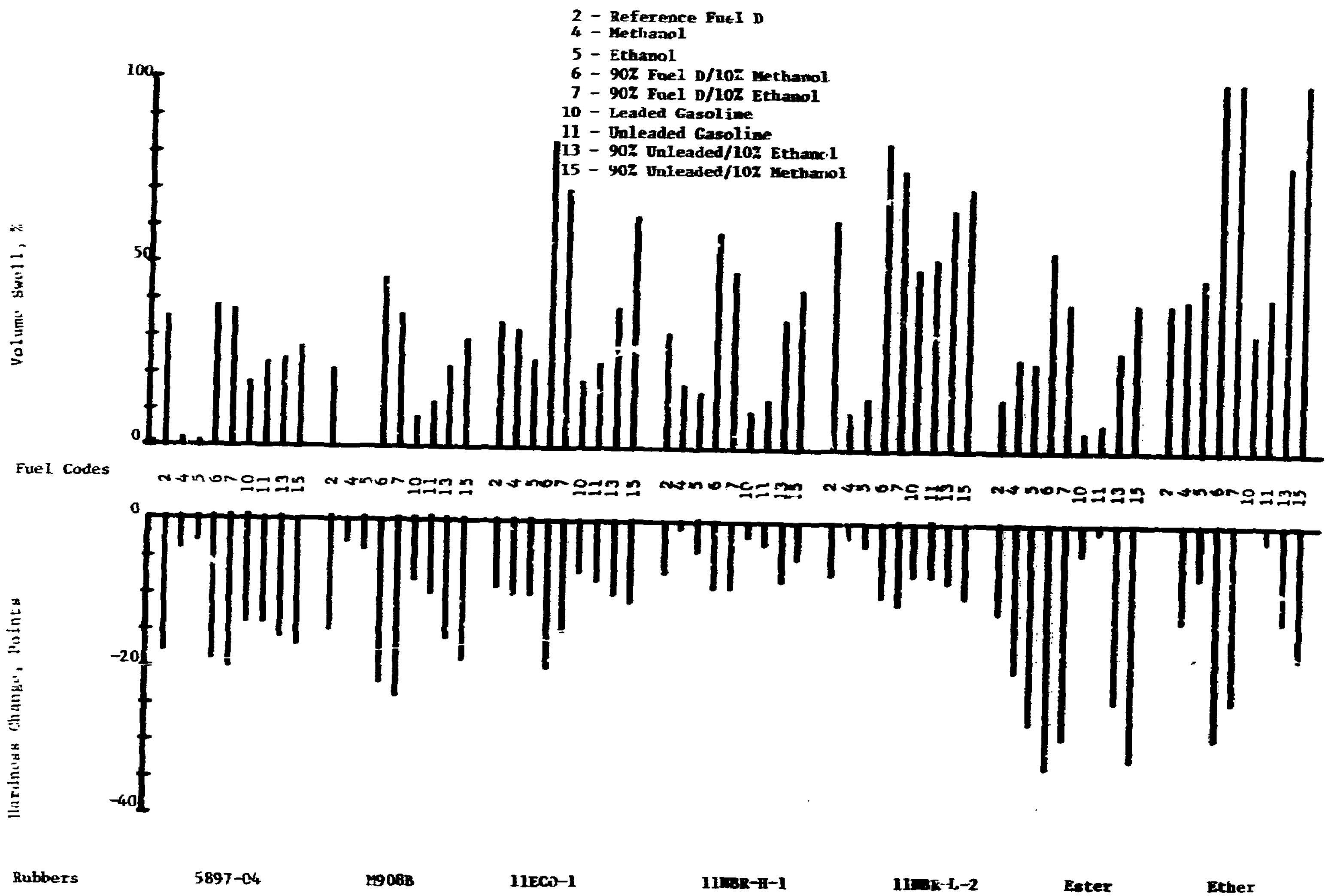

Figure 3. Effect of fuel exposure on the hardness and volume of rubber materials.

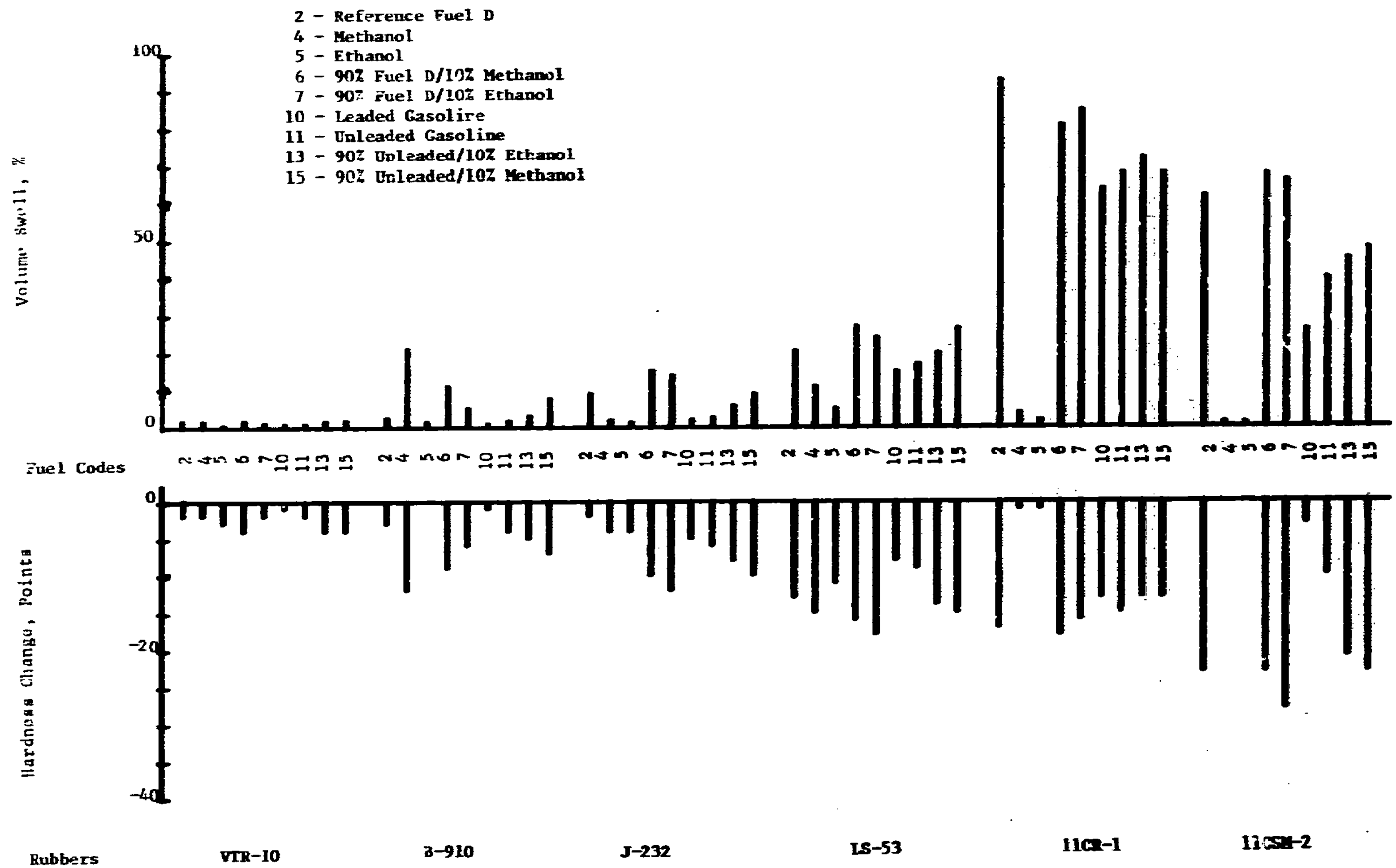

Figure 3. Effect of fuel exposure on the hardness and volume of rubber materials (continued).

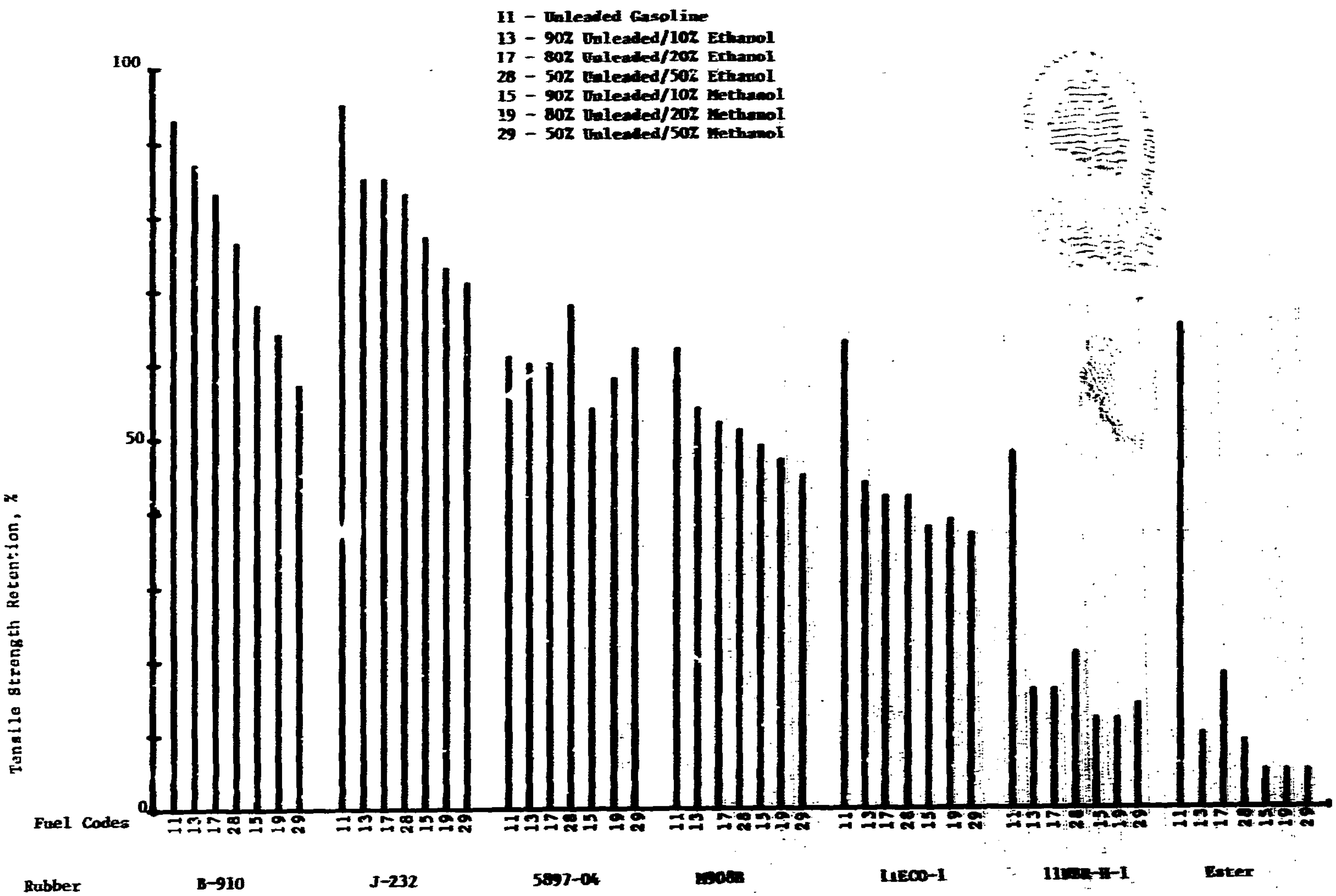

Figure 4. Effect of alcohol concentration on the tensile strength of rubber materials.

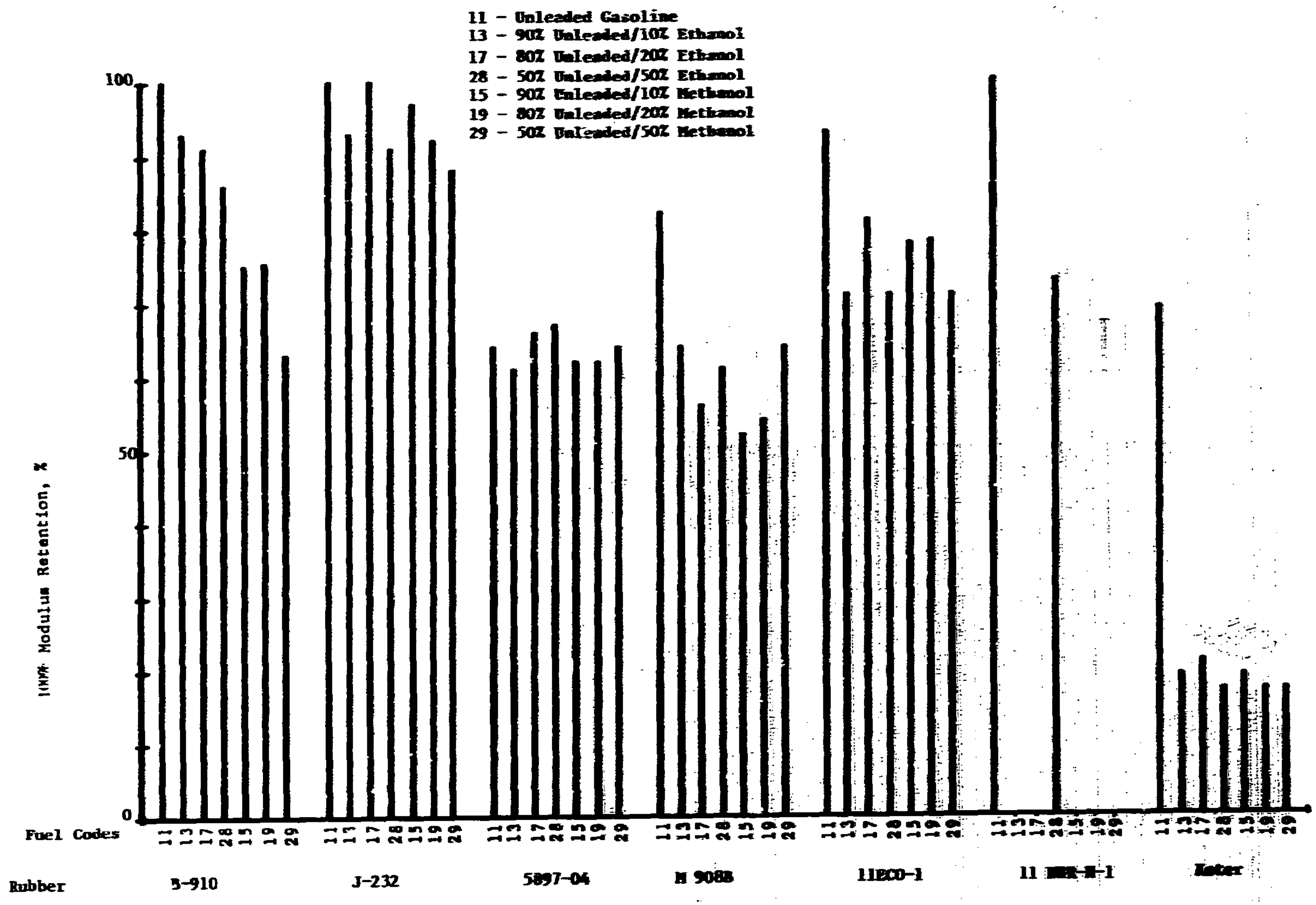

Figure 5. Effect of alcohol concentration on the modulus of rubber materials.

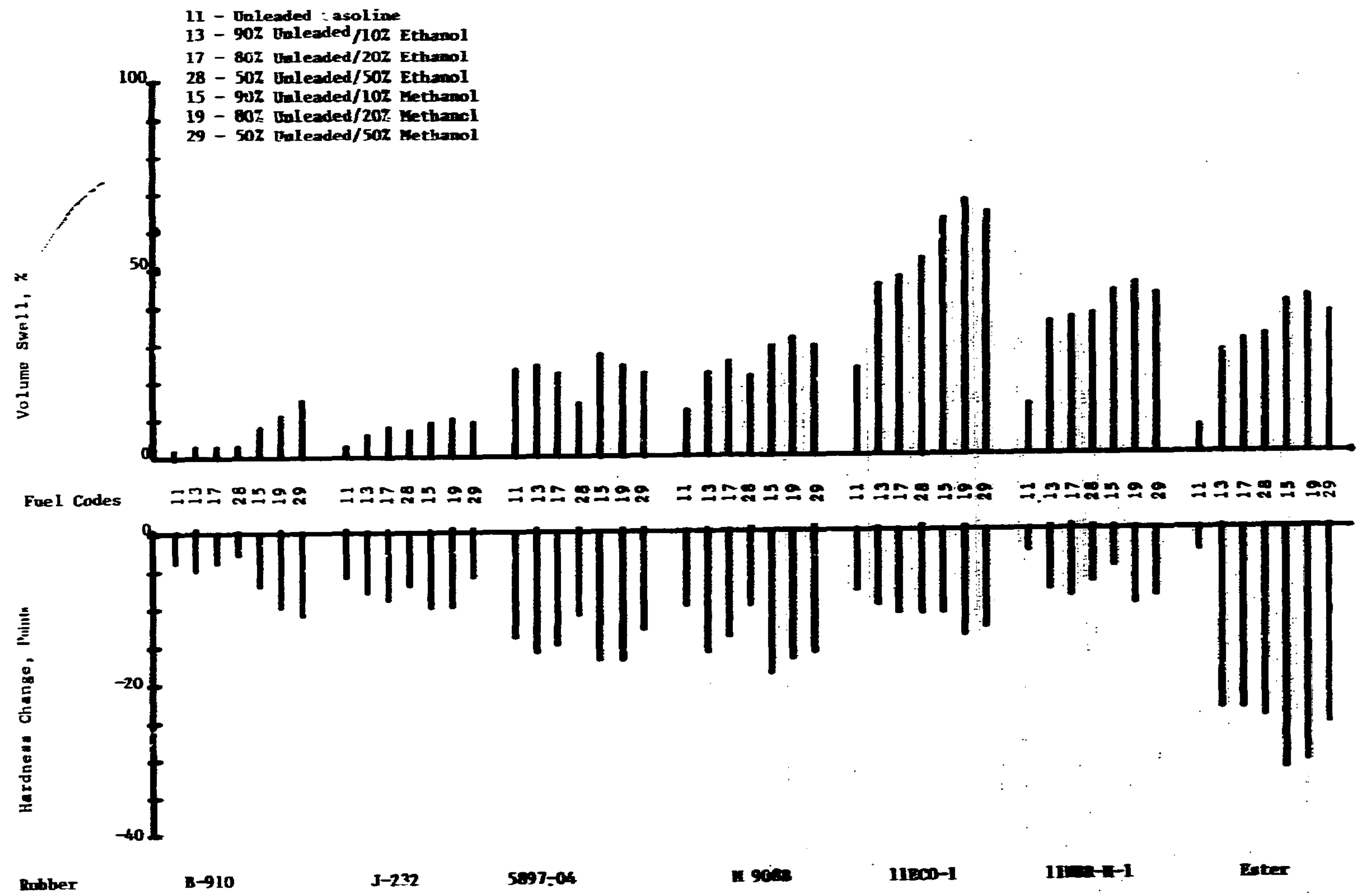

Figure 6. Effect of alcohol concentration of the volume swell and hardness properties of rubber materials.

Fuel No. 13, consisting of 90 percent unleaded gasoline blended with 10 percent ethanol, most closely represents Gasohol as currently supplied commercially for military and civilian use. The bar graph of Figure 7 depicts changes in properties of various rubbers conditioned in this medium. Materials demonstrating the best inherent resistance to Gasohol (high tensile strength retention and low volume swell) include the two fluorocarbons, the polysulfide, and the fluorsilicone compounds. Poorest resistance to Gasohol was observed for the two NBR, the PNT, and the two polyurethane compounds. These data also indicate that chloroprene and CSM rubber can provide better resistance to Gasohol than can the high acrylonitrile rubber; however, these two elastomers are not normally used in applications requiring high resistance to fuels. The low NBR compound, known to display poorer performance in pure gasoline, exhibited properties equivalent to the high NBR materials after exposure to Gasohol. Ether urethane demonstrated better tensile retention but swelled much more severely than did the ester compound. In all cases, degradation of tensile strength was greater than that of elongation, while volume swell of each compound displayed a pattern paralleling that observed for immersion in normal gasolines.

In Figure 8, the relative effects of diesel fuel and diesel fuel containing 5, 10, and 20 percent ethanol on the tensile strength of various elastomers are presented. The best overall resistance to the diesel/alcohol mixture was provided by the fluorocarbons, polysulfide, fluorosilicone, and CSM elastomers, while the least resistance was exhibited by the polyurethanes, nitriles, chloroprene, and PNT-34 (not shown) elastomers. CSM rubber was not significantly affected by the addition of ethanol. CSM, therefore, would be a better choice for use in diesel/alcohol mixtures than any of the rubbers such as urethanes, ECO, and nitriles, now commonly employed in diesel service. For some materials such as M908-B, ECO, the NBR's and urethanes, the substitution of 5 percent alcohol reduced the tensile strength significantly. However, increasing the alcohol content to 20 percent had little additional effect on the tensile strength.

7. Phase II. Only small volume changes were observed in most of the plastic materials exposed to the 12 test fluids, as summerized in Table 10. The highest swell values were exhibited by nylon 6/6 in the fuel mixtures containing leaded gasoline with 20 percent methanol or 20 percent ethanol (27 percent and 28 percent volume increase, respectively).

The specimen dimensions were measured to the nearest ±0.001 in. to facilitate mechanical property determinations. Four plastic materials (acetal, PET, nylon 6/12, and high-density polyethylene) from Tables 11 and 12 showed only minimal changes in both ultimate tensile strength and rupture strength. HDPE exhibited the greatest change reflected as an increase in ultimate tensile strength of about 15 to 20 percent in all fuels. Nylon 6/6 lost a significant amount of strength due to immersion in leaded gasoline mixtures containing 10 percent and 20 percent methanol; a 47 to 48 percent decrease in ultimate tensile and 25 to 27 percent decrease in rupture strength was observed for this material. Glass-filled (Nylon 6/6) showed similar results but to a lesser extent; possibly due to the glass filler content. This indicates that plasticization occurred in these materials. Nylon 6/6 has excellent resistance to gasoline but has been previously observed to decrease in yield stress and increase in elongation as moisture is absorbed. The moisture content of the alcohols may have contributed slightly to this plasticization.

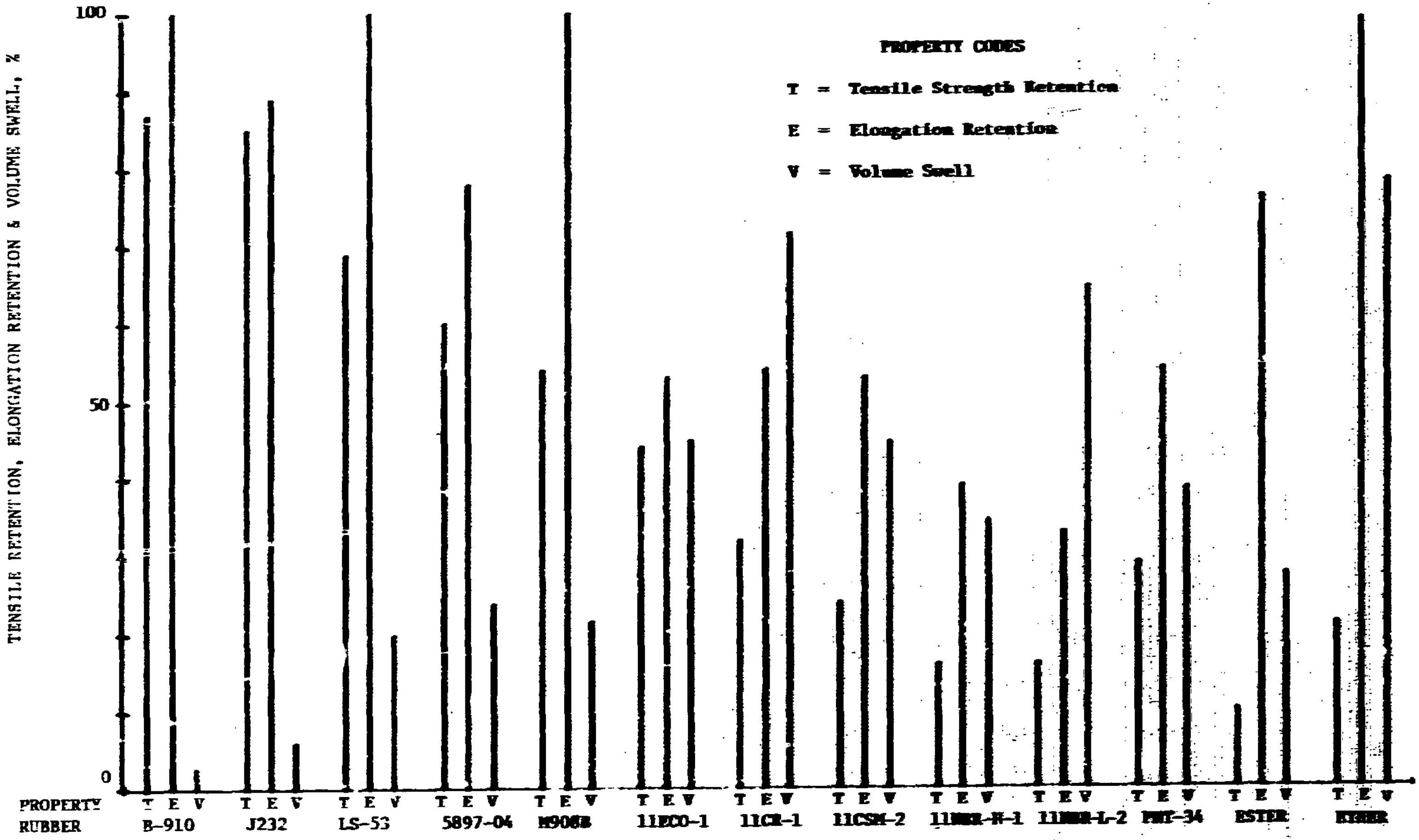

Figure 7. Fuel resistance of rubber materials to gasohol (Fuel No. 13).

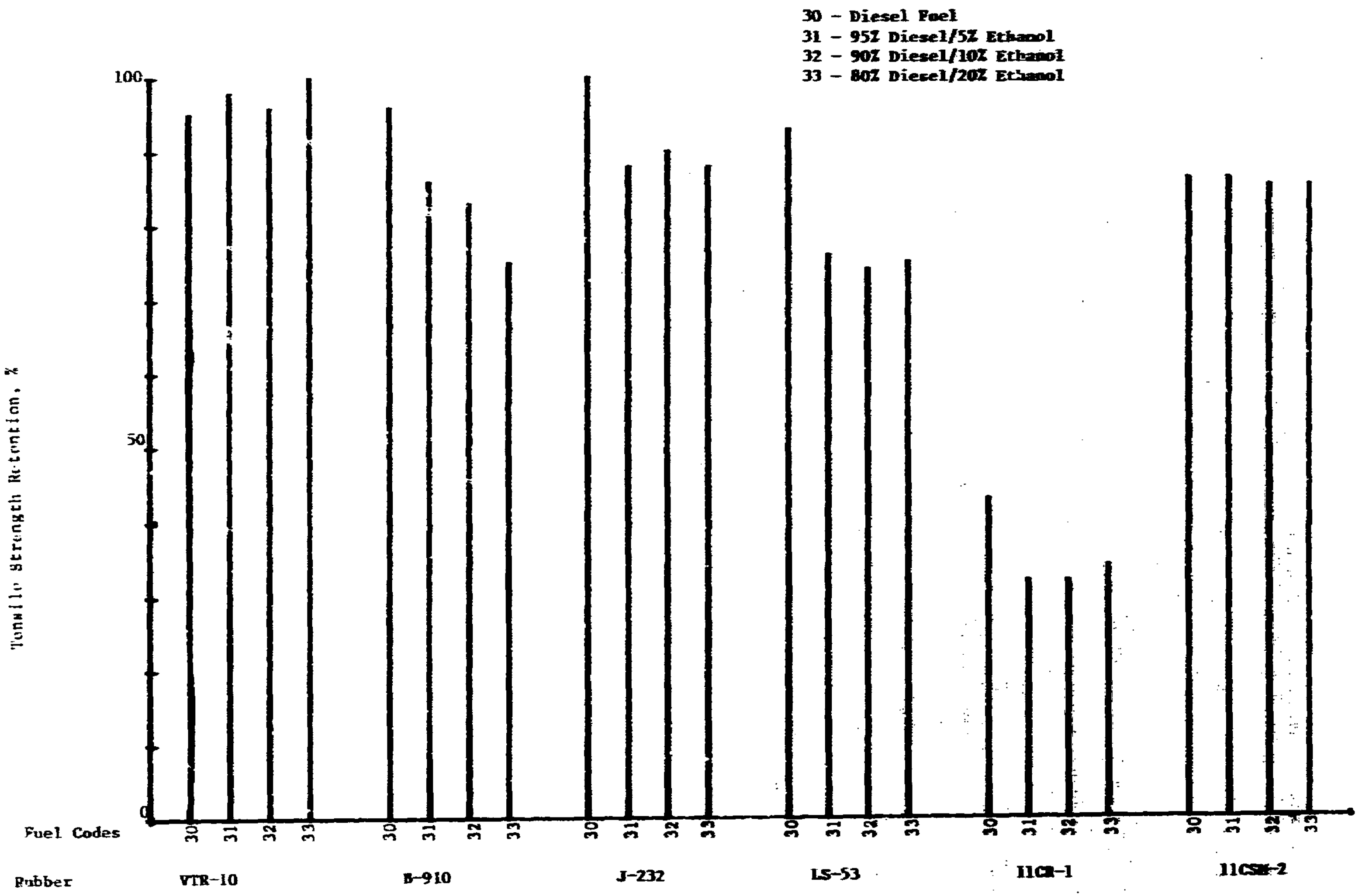

Figure 8. Effect of diesel/alcohol mixtures on tensile properties of rubber materials.

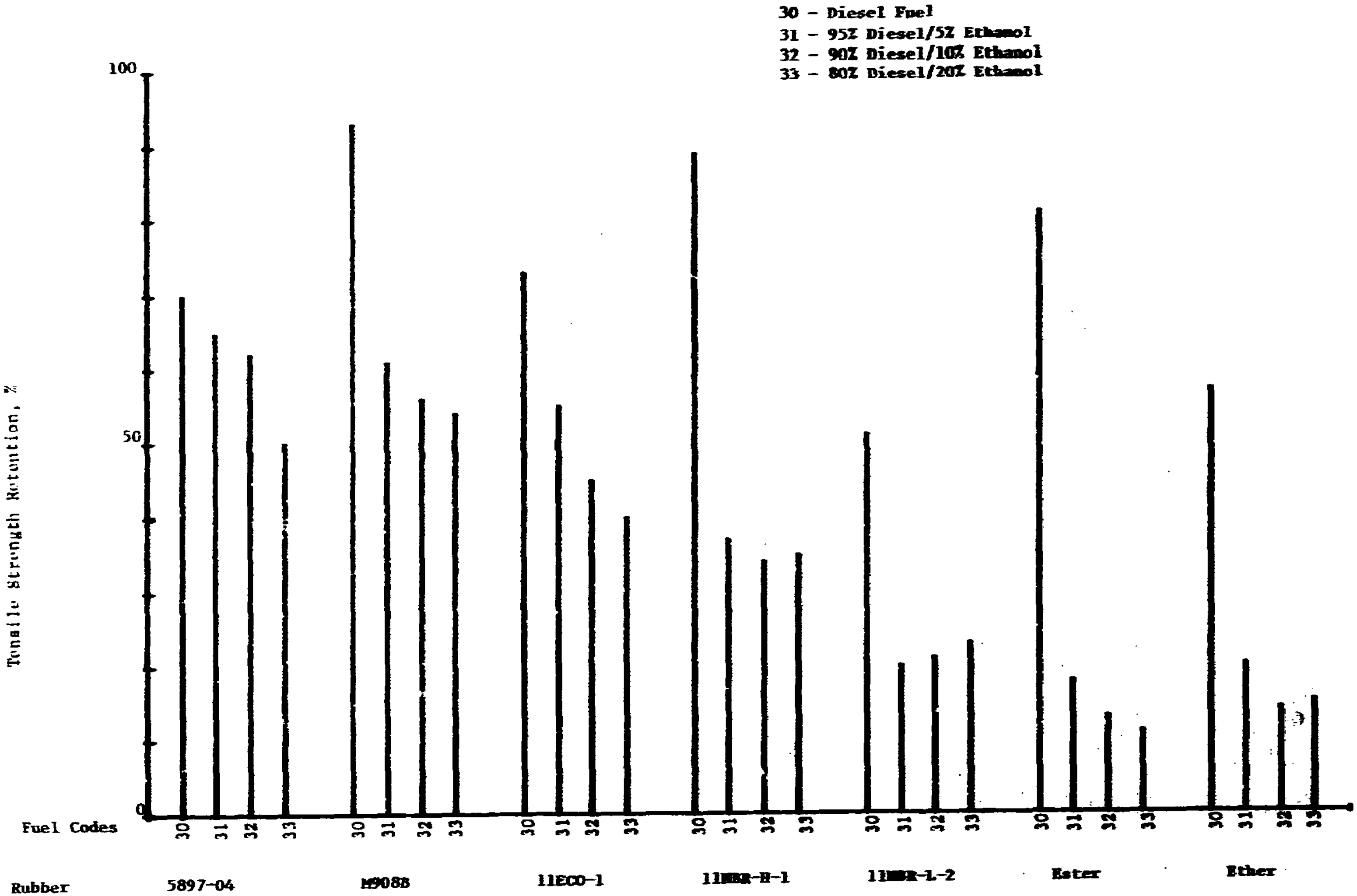

Figure 8. Effect of diesel/alcohol mixtures on tensile properties of rubber materials (continued).

Polypropylene demonstrated a significant loss of yield strength in all fuels but showed an increase in rupture strength. This type of mechanical alteration is also indicative of material plasticization due to the hydrocarbons in fuel/alcohol blends; aromatic hydrocarbons are known for their ability to swell and soften polypropylene. The PBT and phenolic resin samples both exhibited rather inconclusive and incongruous results. In both cases, the ultimate tensile strength and rupture strength were coincident. The PBT specimen immersed in the diesel fuel mixture containing 20 percent ethanol showed a significant increase, but this was not predictable from the other results in the three diesel fuel mixtures. The phenolic resin behaved in a manner similar to HDPE, revealing substantial increases in strength after exposure to all fuels except Reference Fuel B and a 90/10 mixture of leaded gasoline and ethanol.

All the visual results obtained from metal sample inspections with the exception of magnesium were acceptable. No corrosive effects were detected after 28 days of exposure to the various fuels at ambient temperature. Table 13 shows the corrosive results for magnesium samples expressing the change in weight observed after the test period. Methanol had significant effects on magnesium corrosion; 9.6 percent weight loss in leaded gasoline with 10 percent methanol and 20 percent weight loss in leaded gasoline with 20 percent methanol. Magnesium was more resistant to ethanol, exhibiting only 5 percent loss of weight in leaded gasoline with 20 percent ethanol. The lack of visual changes in the pure metals, other than magnesium, probably is due to the short immersion period and room temperature conditions selected in this program.

The epoxy-coated metal results were consistent with what can be expected for epoxy resistance to moisture (Table 14). The major effects of immersion were seen in leaded gasoline/methanol mixtures. The changes observed in these fuels ranged from color absorption to metal corrosion. The epoxy coating on the metals was difficult to maintain at a uniform thickness. Consideration must also be given to possible pinhole porosity in the coating which might aid in the absorption of fuel by the epoxy and subsequent corrosion of the metal.

8. Phase III. Results for test fuel/material compatibility are shown in graphical and tabular format and include determinations of specific gravity, unwashed and washed gums, and percent residue distillation. Distillation data for all ranges are in Tables 31 and 32.

a. Specific Gravity.

(1) Elastomers. The base specific gravity of ethanol and methanol is approximately 0.05 greater than that of fuels used in this study. Pure unleaded fuel displayed a value of 0.005 higher than leaded fuel. The substitution of 10 percent or 20 percent ethanol or methanol in the leaded fuel resulted in similar noticeable proportionate increases in specific gravity. However, substitution of the alcohols in the unleaded fuel produced different results—a lesser increase in specific gravity at the 10 percent level for both additives, and a slight decrease when methanol content was raised to 20 percent. Substitution of 10 percent of both methanol and ethanol in the unleaded fuel resulted in a specific gravity significantly higher than that of any of the other blends. The specific gravities of the various test fuels in which the elastomers had been conditioned are depicted in Figures 9 through 16.

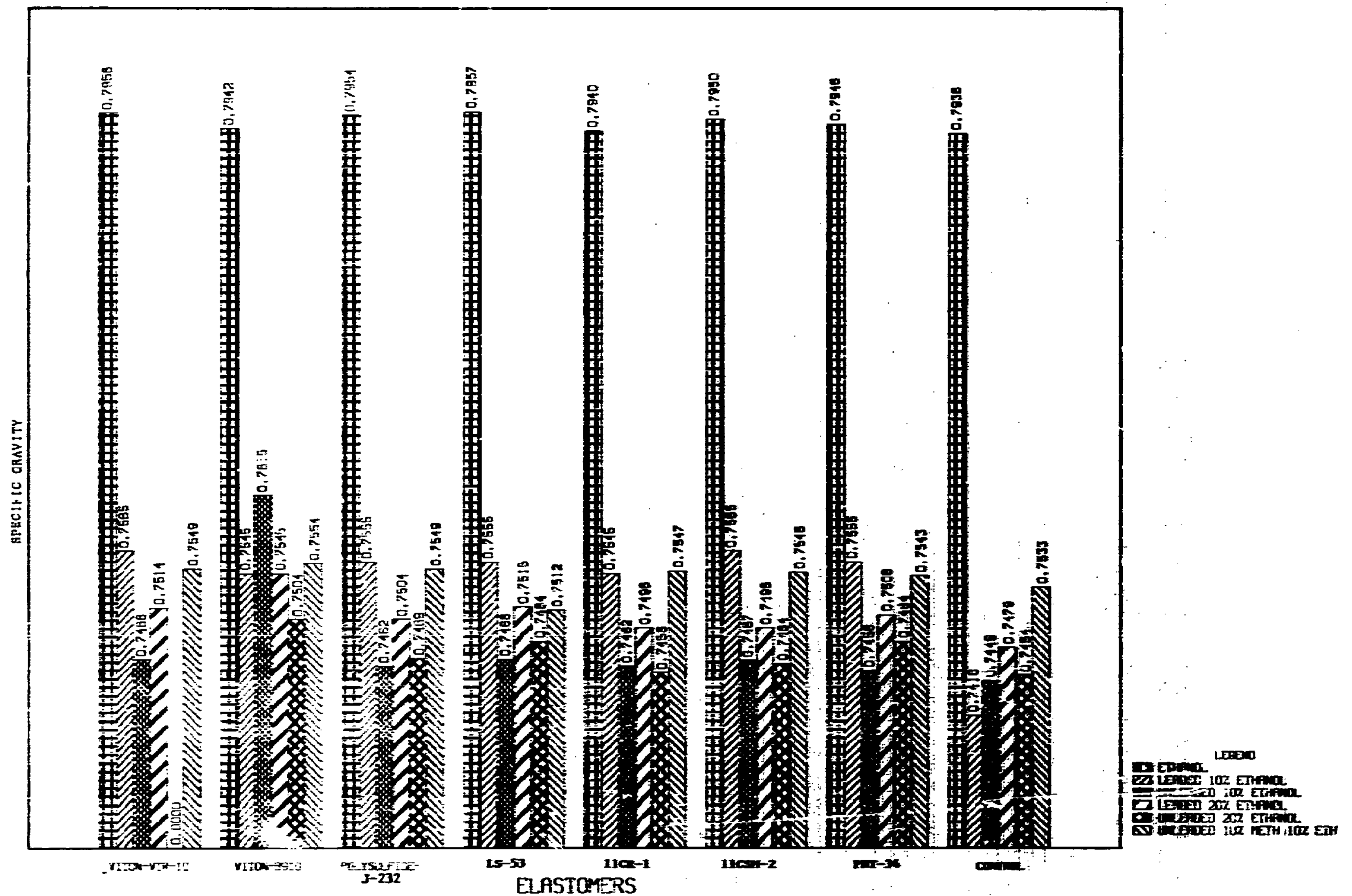

Figure 9. Specific gravity of test fuels conditioned with elastomers.

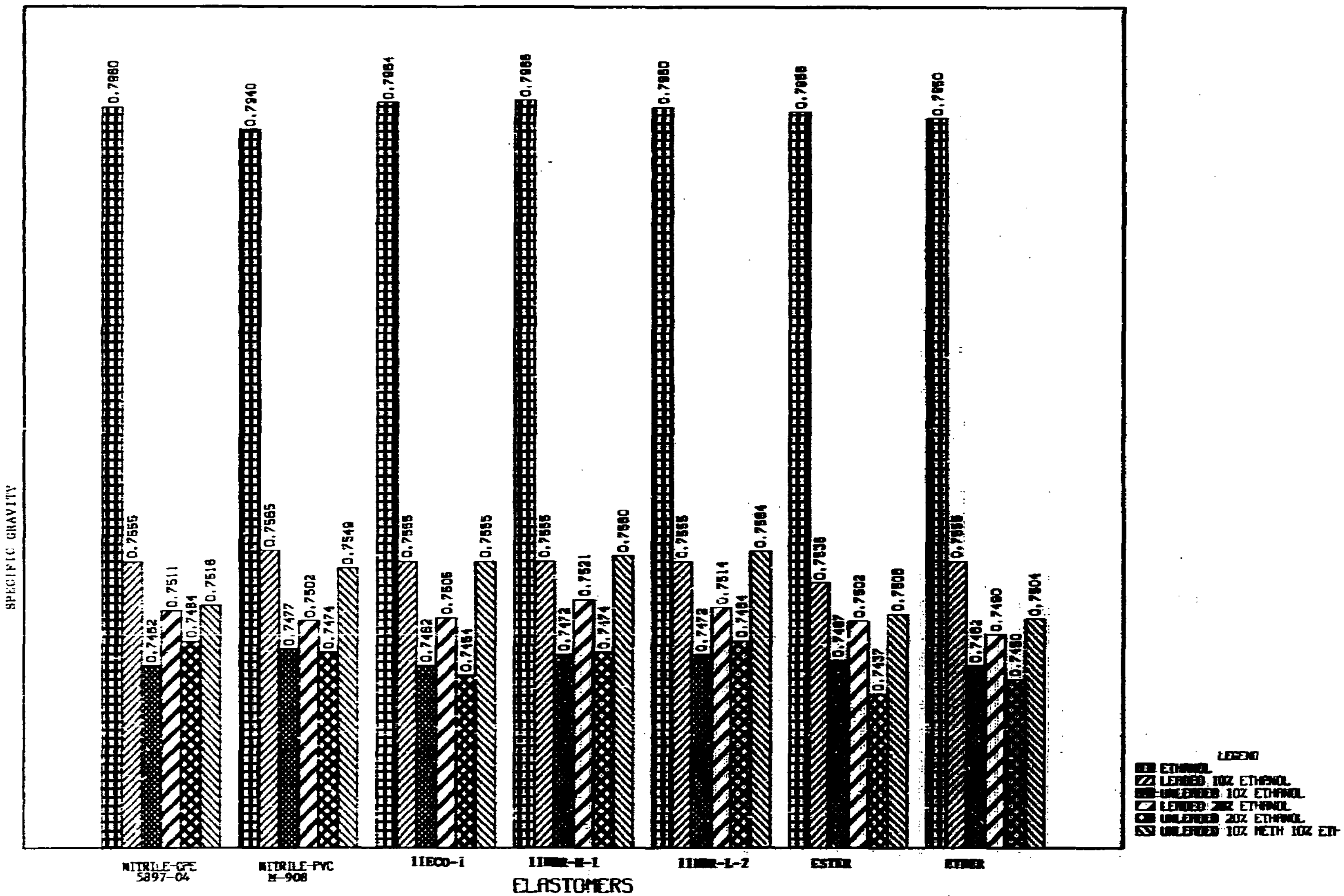

Figure 10. Specific gravity of test fuels conditioned with elastomers.

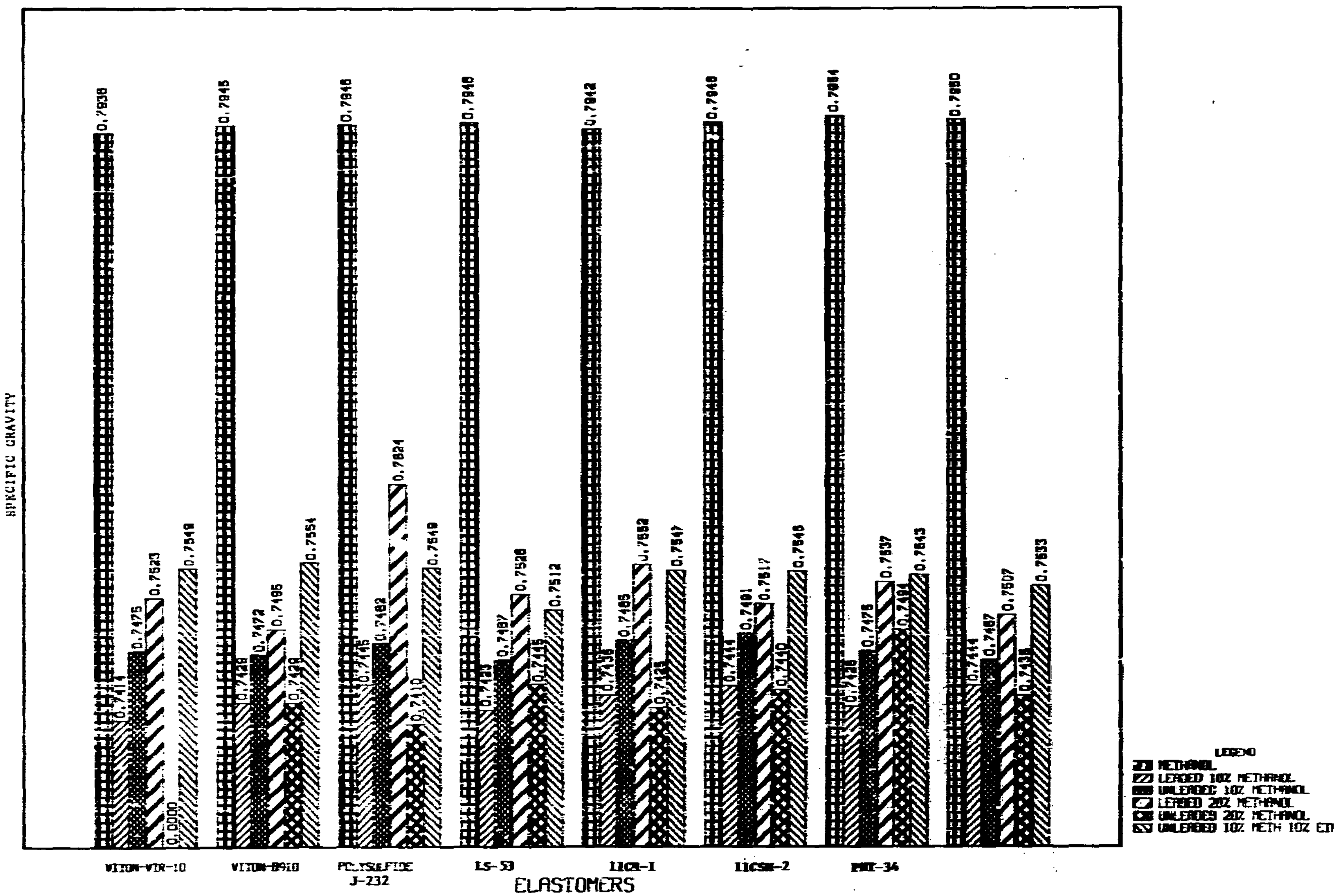

Figure 11. Specific gravity of test fuels conditioned with elastomers.

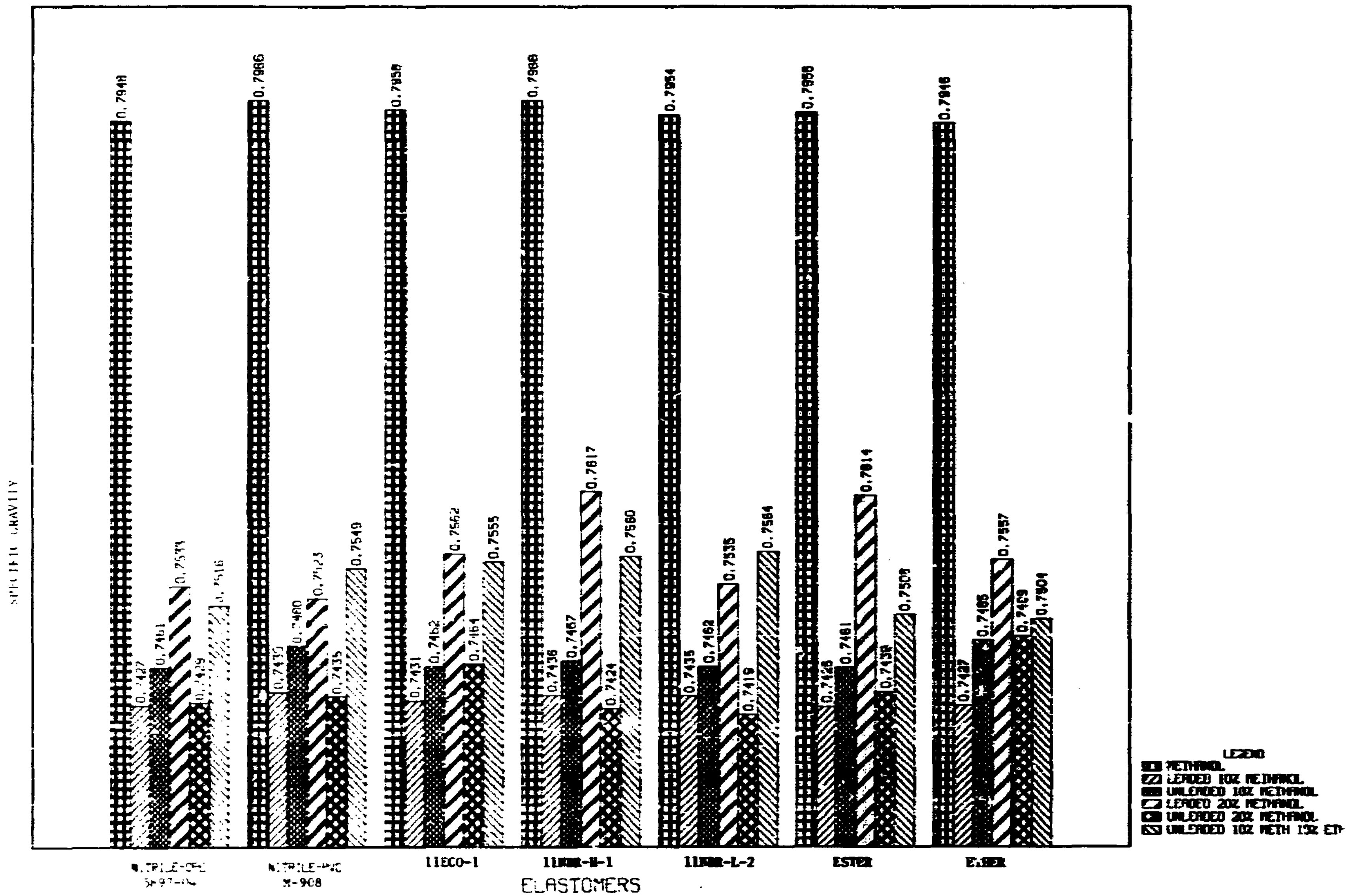

Figure 12. Specific gravity of test fuels conditioned with elastomers.

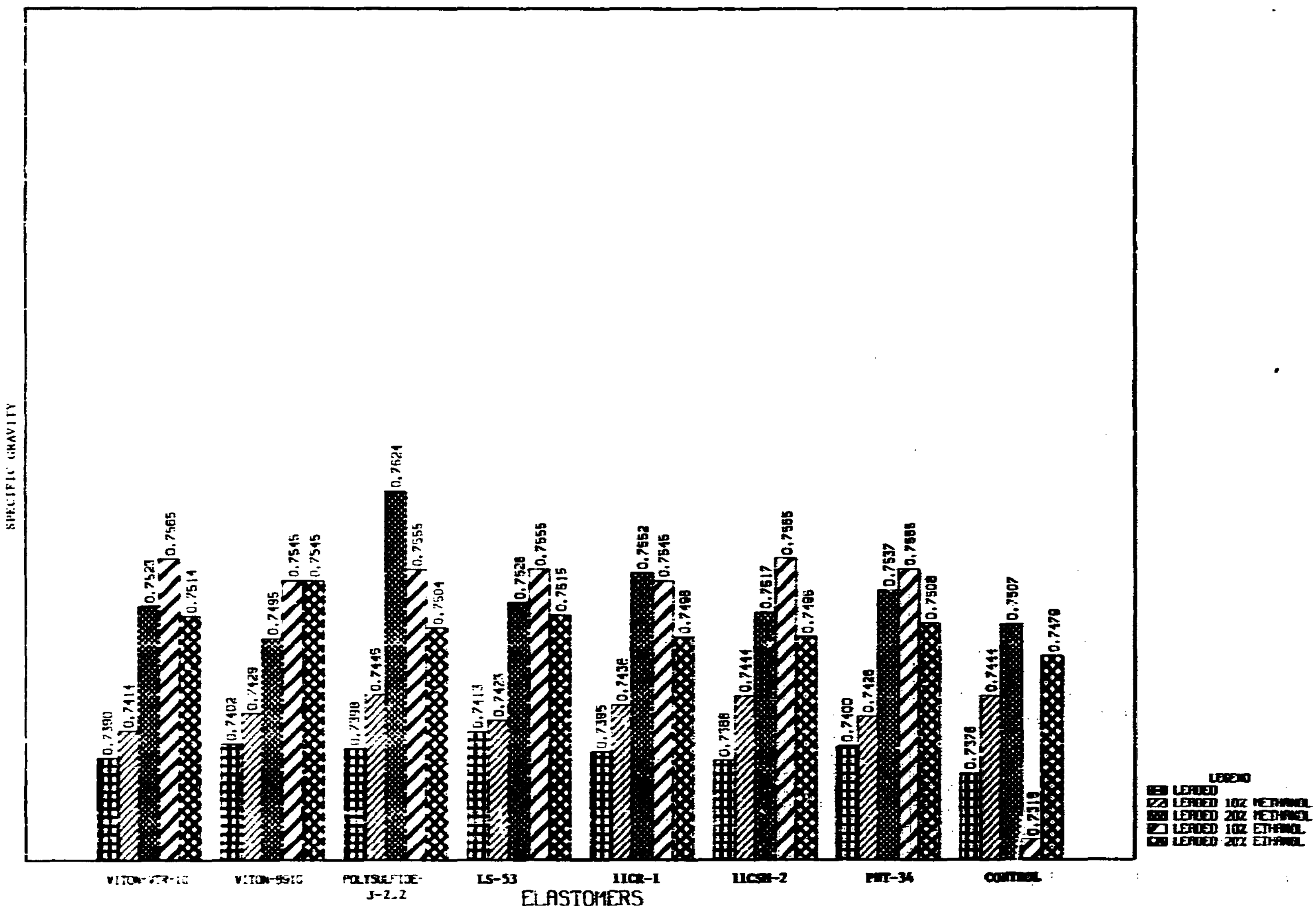

Figure 13. Specific gravity of test fuels conditioned with elastomers.

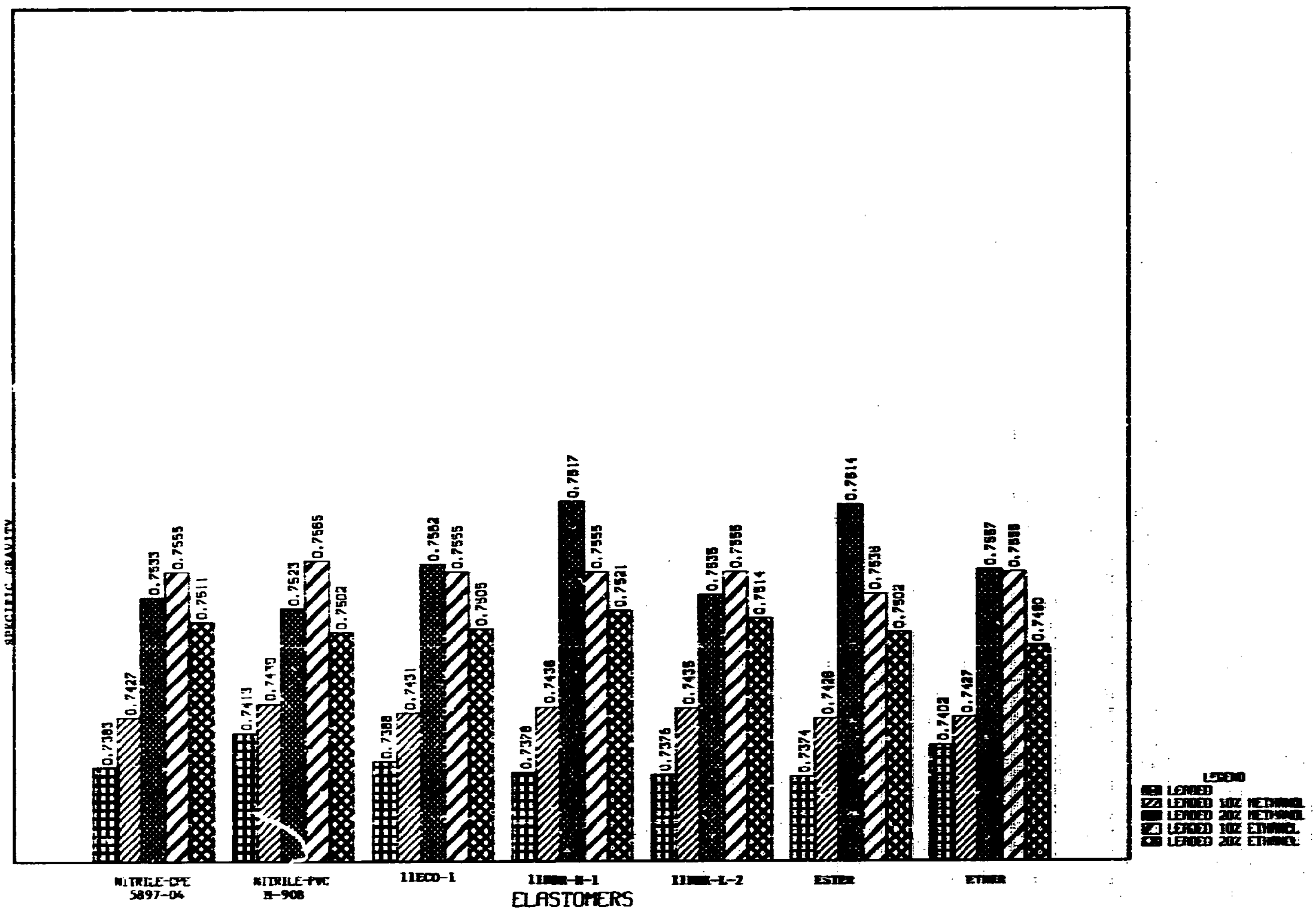

Figure 14. Specific gravity of test fuels conditioned with elastomers.

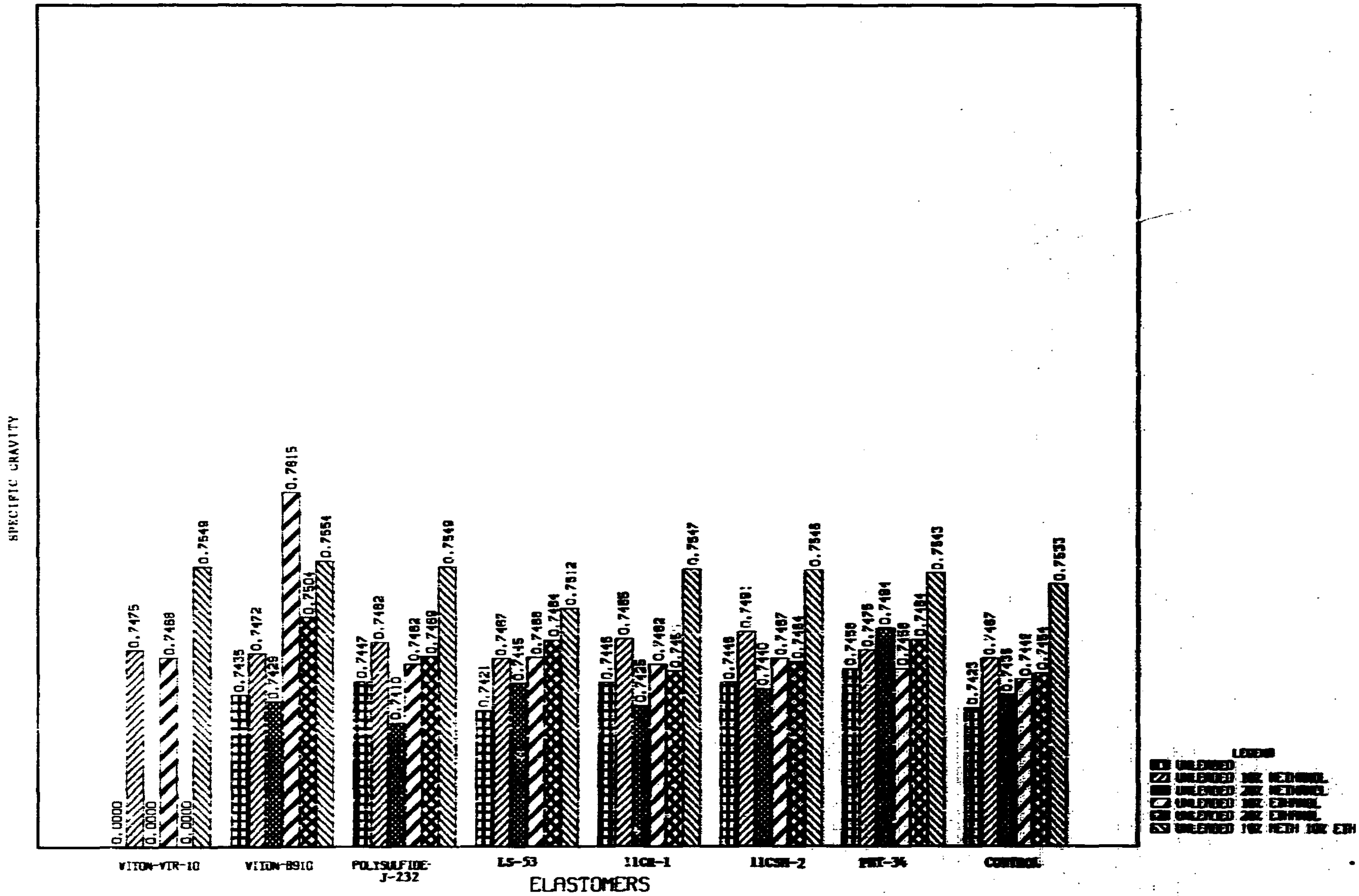

Figure 15. Specific gravity of test fuels conditioned with elastomers.

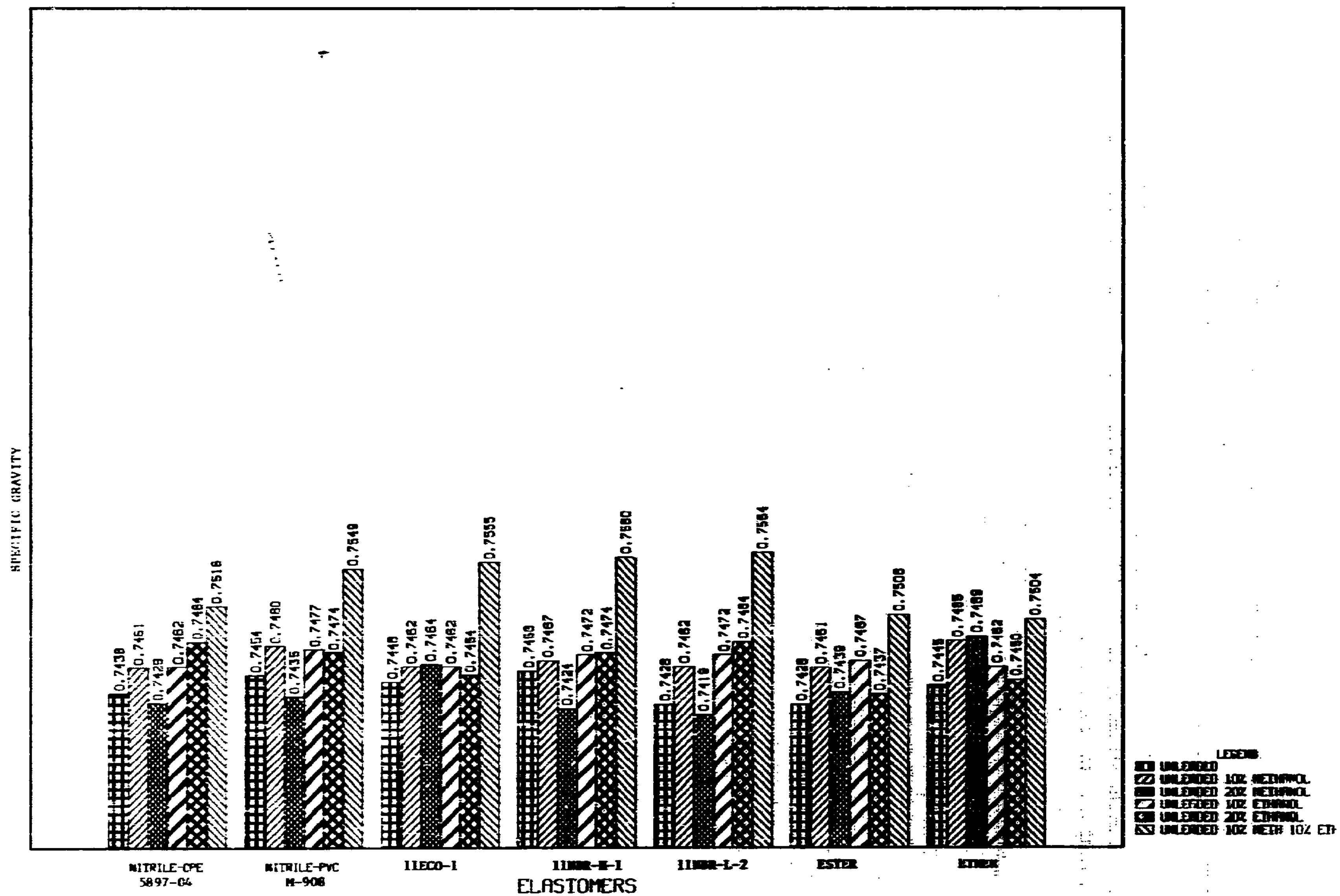

Figure 16. Specific gravity of test fuels conditioned with elastomers.

In all cases where an elastomer was exposed in a leaded blend, a distinct pattern in specific gravity changes was observed. Values for all 10 percent ethanol blends increased noticeably but then dropped at the 20 percent ethanol level, and in some cases being again equal to or lower than that of the control. Exposure of the elastomers in the leaded fuel/methanol blends always resulted in higher values at the 20 percent methanol level as opposed to the 10 percent level, but the specific gravity in the latter case was sometimes lower than that of the control.

No clear pattern evolved relative to changes in specific gravity when the various elastomers were exposed in unleaded fuel/alcohol blends. Changes were generally less pronounced. Except for the significant rise noted for the Viton B-910 compound/10 percent ethanol exposure, translation of these data into a meaningful analysis of unleaded gasohol/rubber compatibility is virtually impossible.

Earlier work by this laboratory has established that unleaded gasolines, by virtue of their higher aromatic content, have a more deleterious effect on conventional fuel resistant elastomers. The more pronounced changes in specific gravity noted for the leaded blends could be interpreted as an indication that these fuels might instead be more deleterious; i.e., equating the changes to leaching out of the rubber compound's constituents and/or replacement with components of the fuel. Obviously, exact interpretation of elastomer/fuel compatibility cannot be discerned from specific gravity data alone.

(2) Plastics. Significant changes in specific gravities were observed for polypropylene and to a lesser extent nylon 6/12 in leaded 20 percent ethanol fuels (see Figures 17 through 20). The leaded PBT series, as a whole, was the least affected. The unleaded series was more consistent than the leaded series, and the two plastics which contributed significant changes were HDPE and nylon 6/12. The phenolic plastic, when exposed to leaded/10 percent methanol, effected greater increase than its 10 percent ethanol counterpart. With the exception of HDPE, the combination fuel (80/10/10) did not effect any major changes. Pure ethanol and methanol gravities did not change with the exception of the nylon 6/6 in methanol.

(3) Metals. The specific gravities for the various metal-fuel/alcohol combinations do not show any significant changes in the fuel properties (see Figures 21 through 24). The controls of leaded/20 percent ethanol and leaded/10 percent methanol displayed higher values than the metal series counterparts. However, these values are considered within the experimental range and not significant.

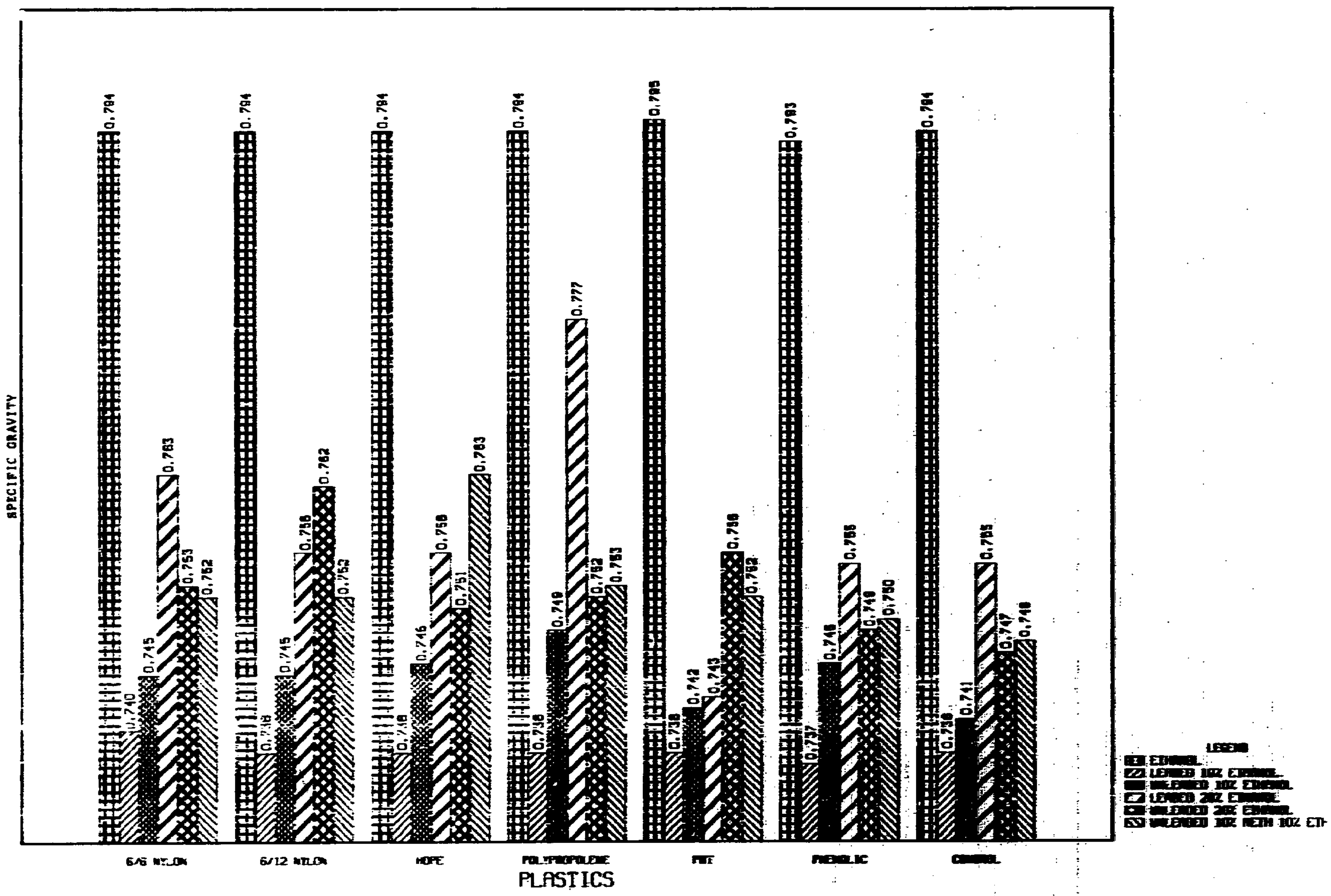

Figure 17. Specific gravity of test fuels conditioned with plastics.

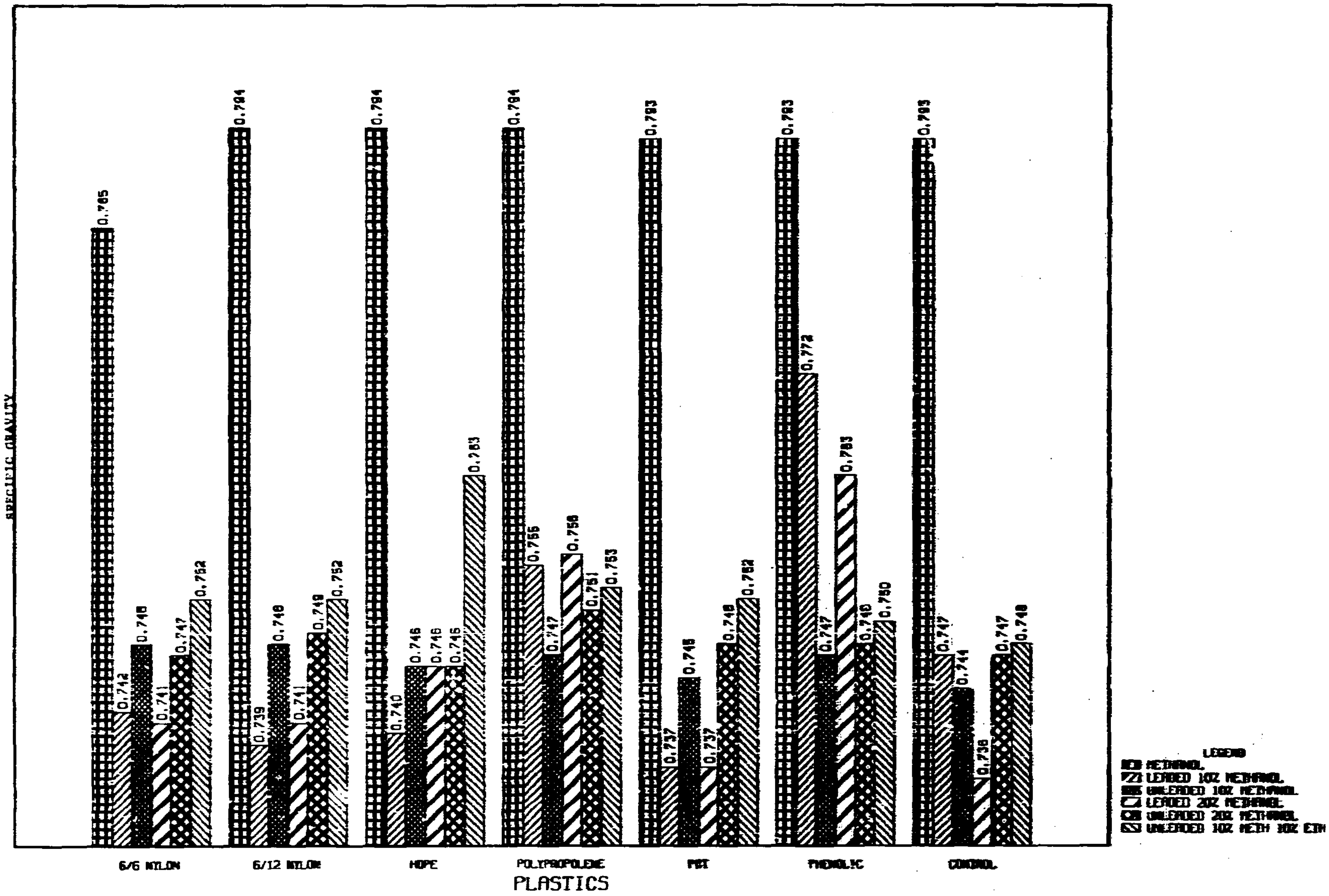

Figure 18. Specific gravity of test fuels conditioned with plastics.

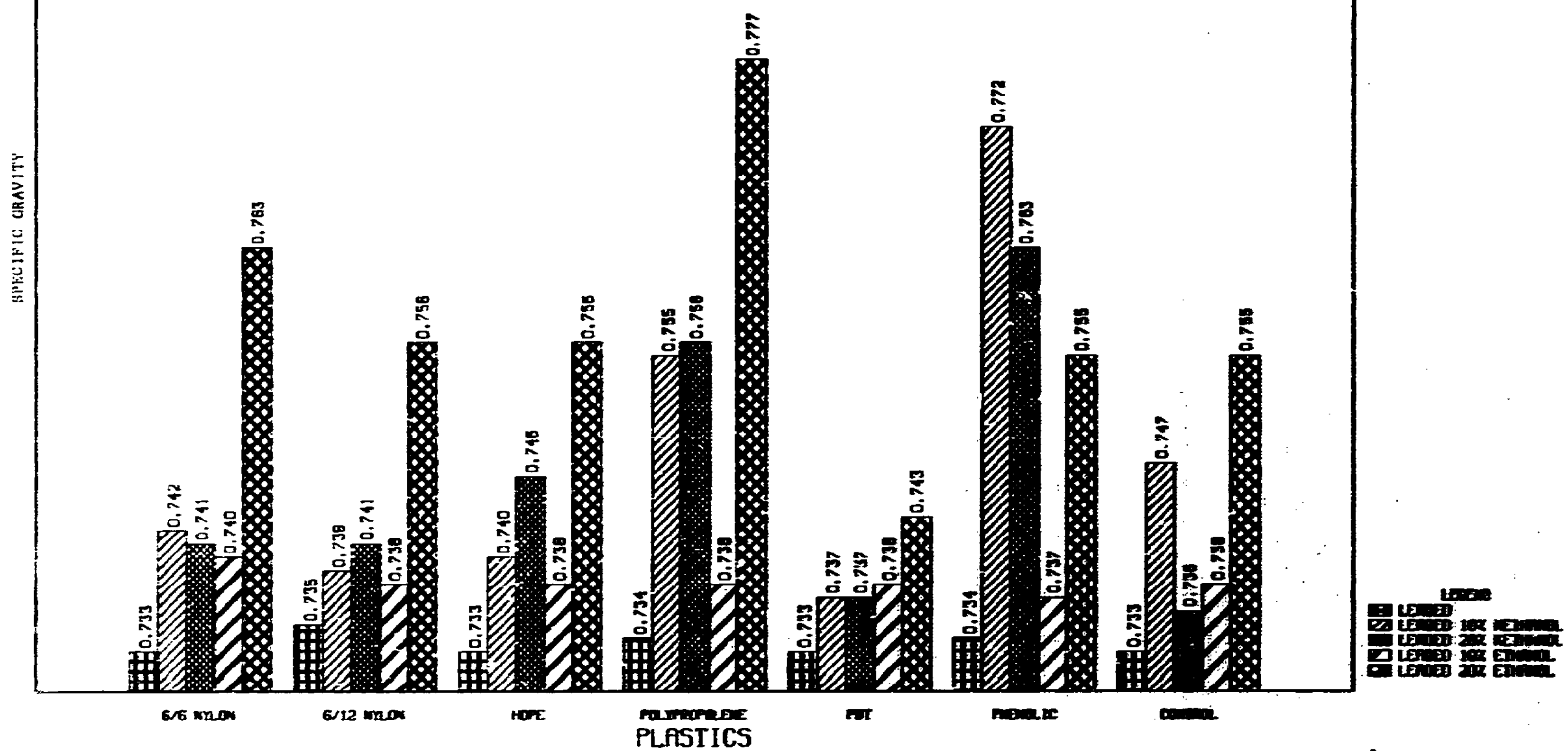

Figure 19. Specific gravity of test fuels conditioned with plastics.

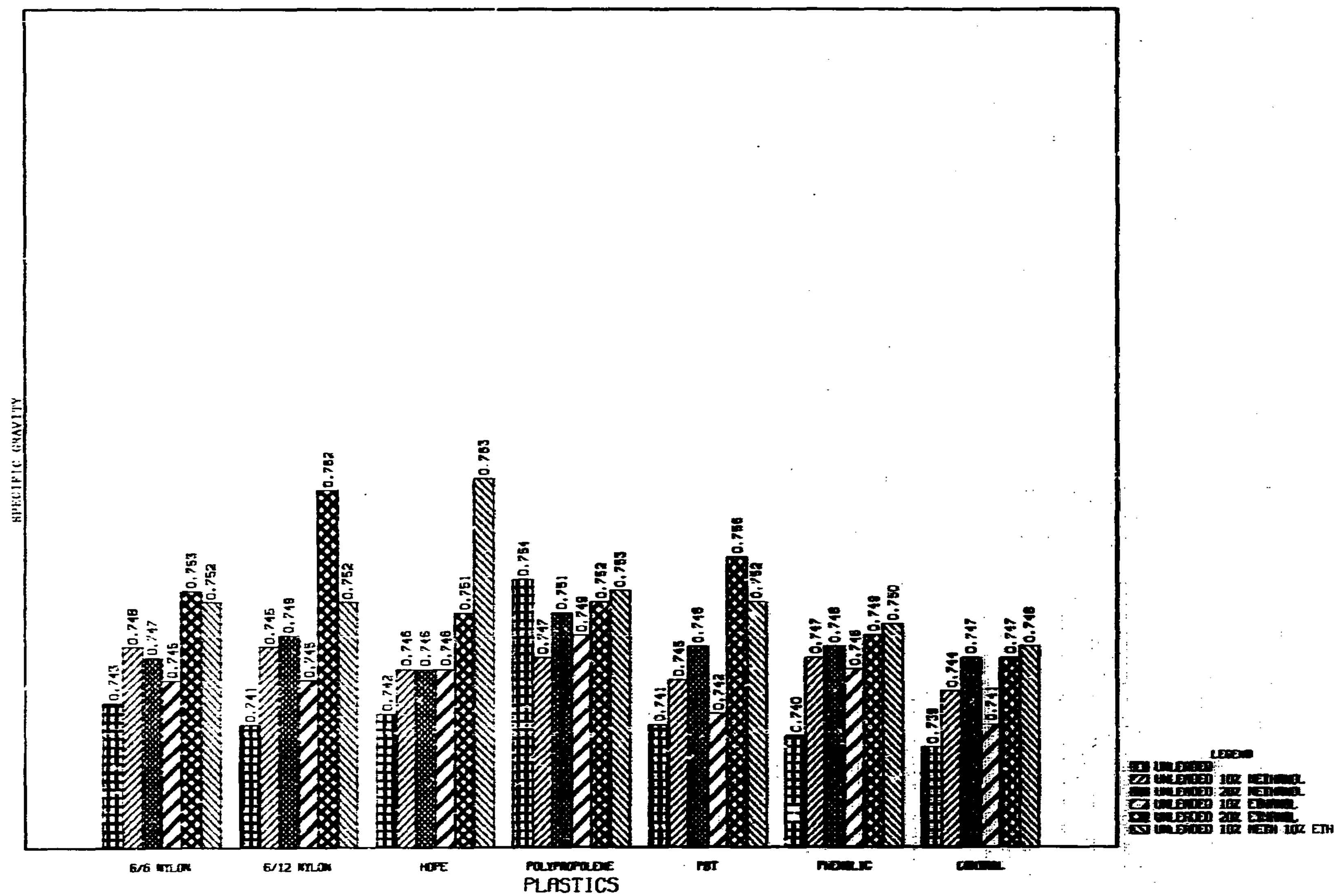

Figure 20. Specific gravity of test fuels conditioned with plastics.

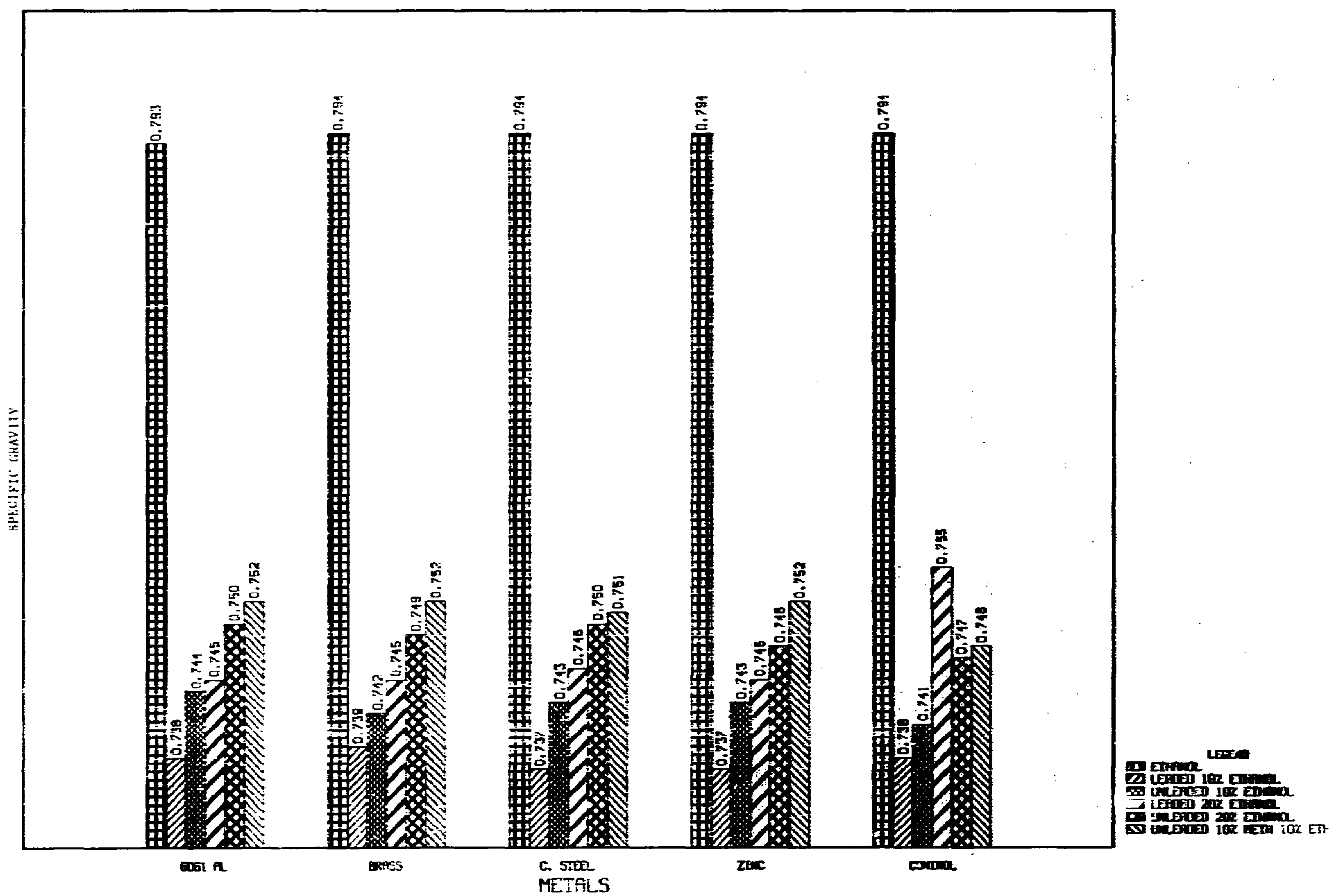

Figure 21. Specific gravity of test fuels conditioned with metals.

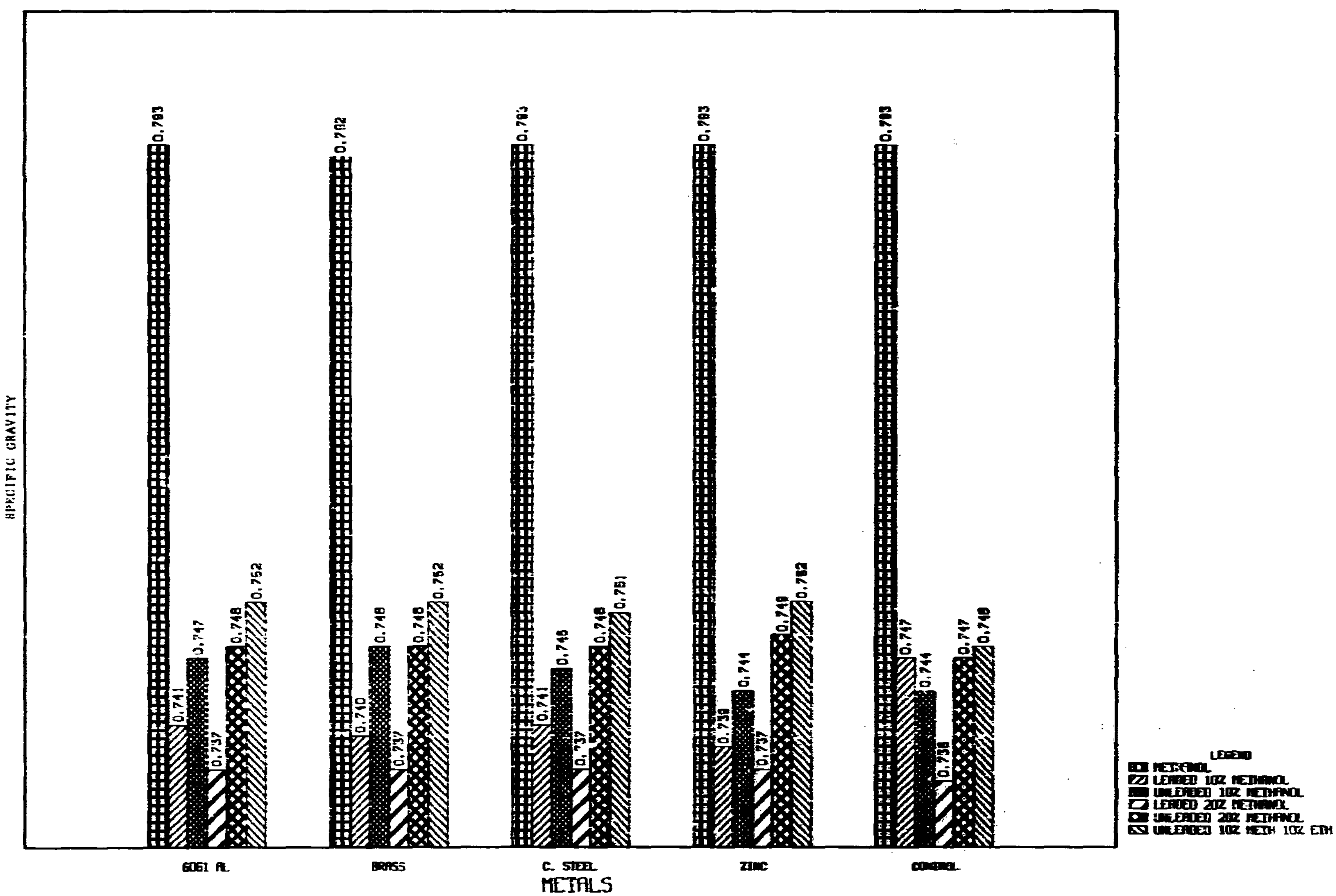

Figure 22. Specific gravity of test fuels conditioned with metals.

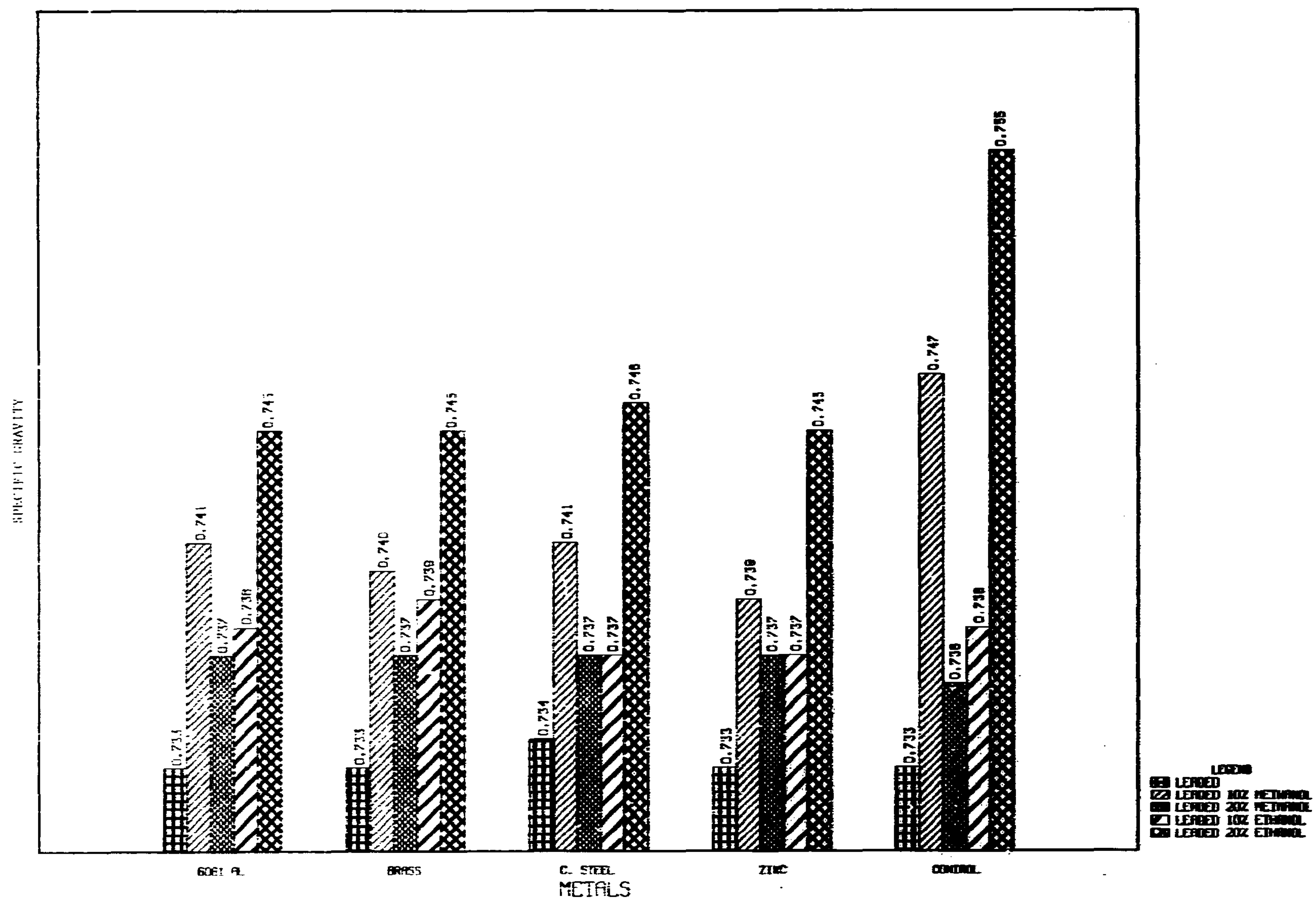

Figure 23. Specific gravity of test fuels conditioned with metals.

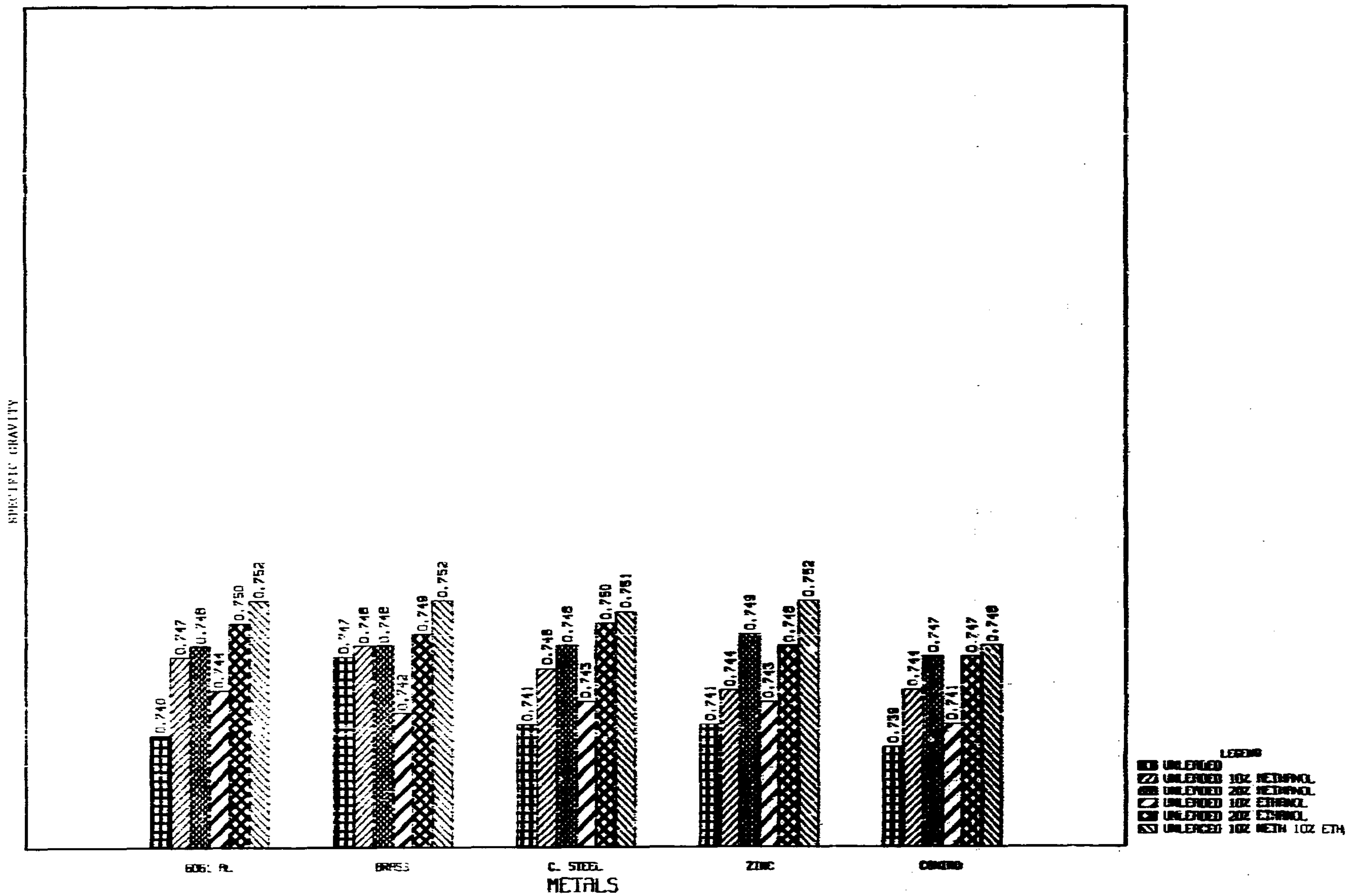

Figure 24. Specific gravity of test fuels conditioned with metals.

b. Unwashed and Washed Gums.

(1) **Elastomers.** Optimization of fuel performance is contingent upon minimizing the so-called unwashed (existent) and washed-gum content; i.e., insoluble residues which can accumulate and foul engine performance. Generally accepted maximum values for unwashed gum vary from a low 3 mg/100 ml for aviation gasoline to 10 mg/100 ml for automobile gasoline, and no current limit for gasohol blends. Washed gum limits are primarily set at the 3 mg to 5 mg/100 ml level for most fuels with the latter value currently under consideration for Gasohol. Control values for the leaded fuel and its alcohol blends fell within these limits, while corresponding unwashed gum values for the unleaded fuel and its blend with 10/10 methanol/ethanol were significantly higher as was the washed gum value for that blend.

As is vividly demonstrated in the data tables and graphs (see Figures 25 through 40) exposure of typical fuel-resistant elastomers in leaded and unleaded fuels and their alcohol blends almost always results in significant increases in unwashed and washed gum content. However, these data must be viewed properly as a worst case situation, in that rubber compound samples were powdered in a mill prior to exposure, resulting in maximum exposed surface area. Thus, gum content values would be considerably higher than those normally obtained from diced compound samples as is usually required in end item specifications.

Comparison of gum content data for leaded vs. unleaded fuels and their alcohol blends does not reveal any distinct trend or pattern. In fact, several anomalies, such as reduced or abnormally higher gum content increase when the alcohol portion of a blend was increased, insignificant changes or values lower than those of the controls were observed. Nevertheless, some obvious conclusions can be derived.

Viton and fluorosilicone compounds contribute the least in terms of fuel gum contamination and are to be preferred for usage where this factor is critical. High nitrile-content NBR rubber, known to be superior in fuel resistance to its low nitrile counterpart, displays both washed and unwashed gum values essentially equivalent to those of the latter. The consistently higher values for ester urethane vs. the ether type, emphasize preference for the ethers. Phosphazene rubber values were high considering the material's known good resistance to fuel deterioration. However, it must be considered that the urethanes and especially phosphazene have demonstrated poor retention of properties when exposed to alcohol blends. Neoprene, used extensively in applications such as fuel hose and gaskets, along with polysulfide and the nitrile blends, evidenced the highest level of unwashed gum contamination. This tendency persists when a comparison among the washed gum values is made. Hypalon and ECO, which display intermediate unwashed gum values, tend to show proportionately higher washed gum values than would be expected.

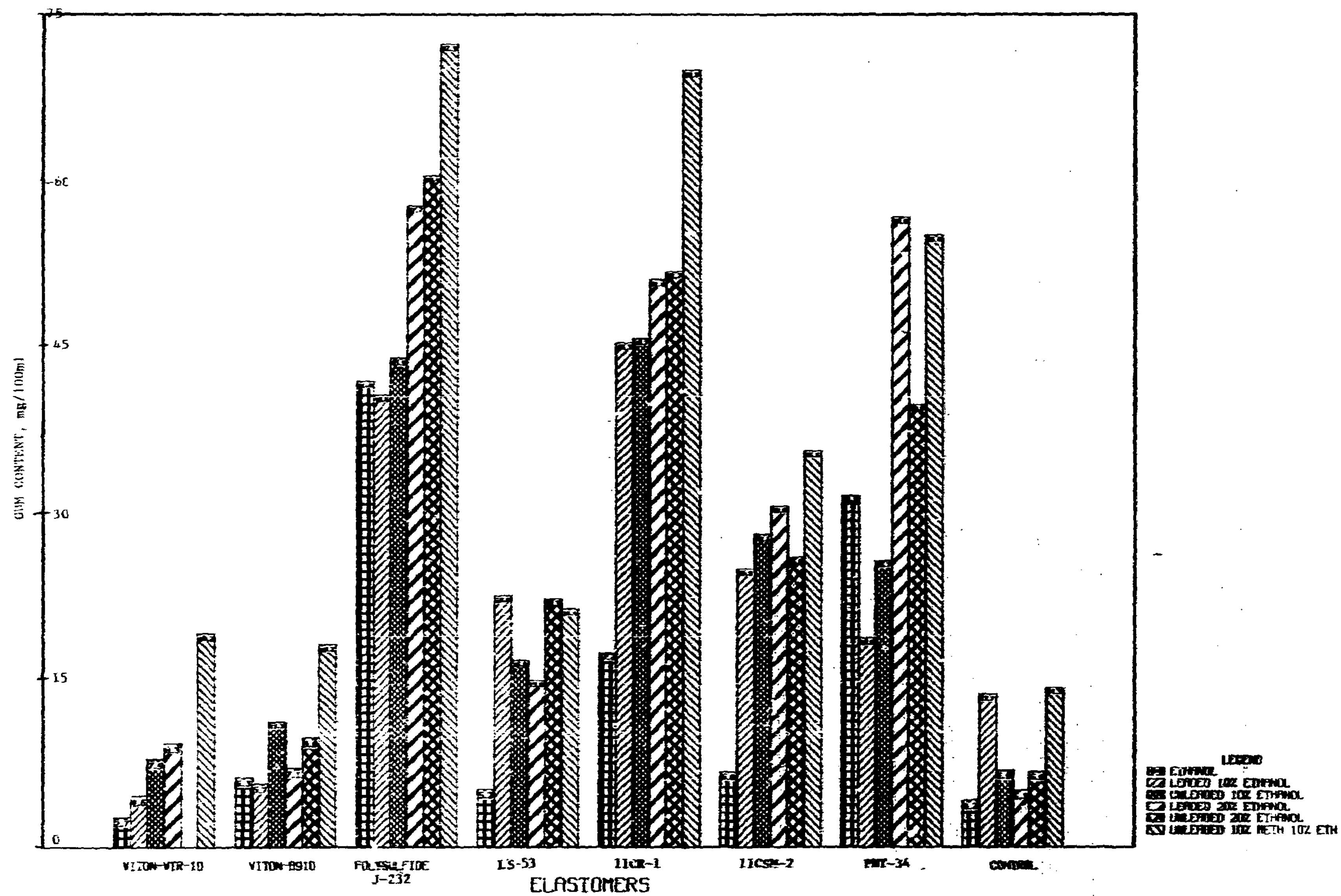

Figure 25. Unwashed gum content of test fuels conditioned with elastomers.

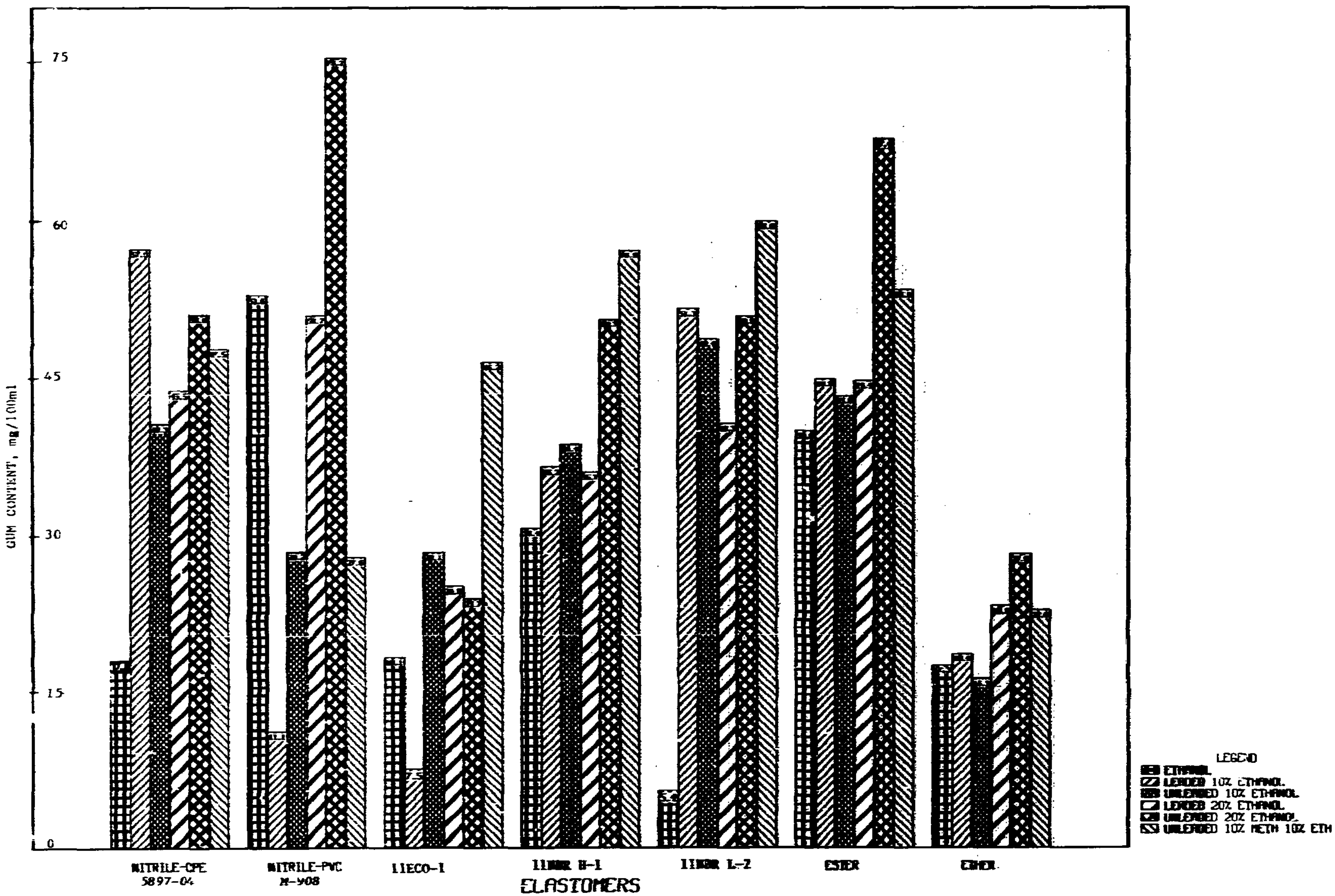

Figure 26. Unwashed gum content of test fuels conditioned with elastomers.

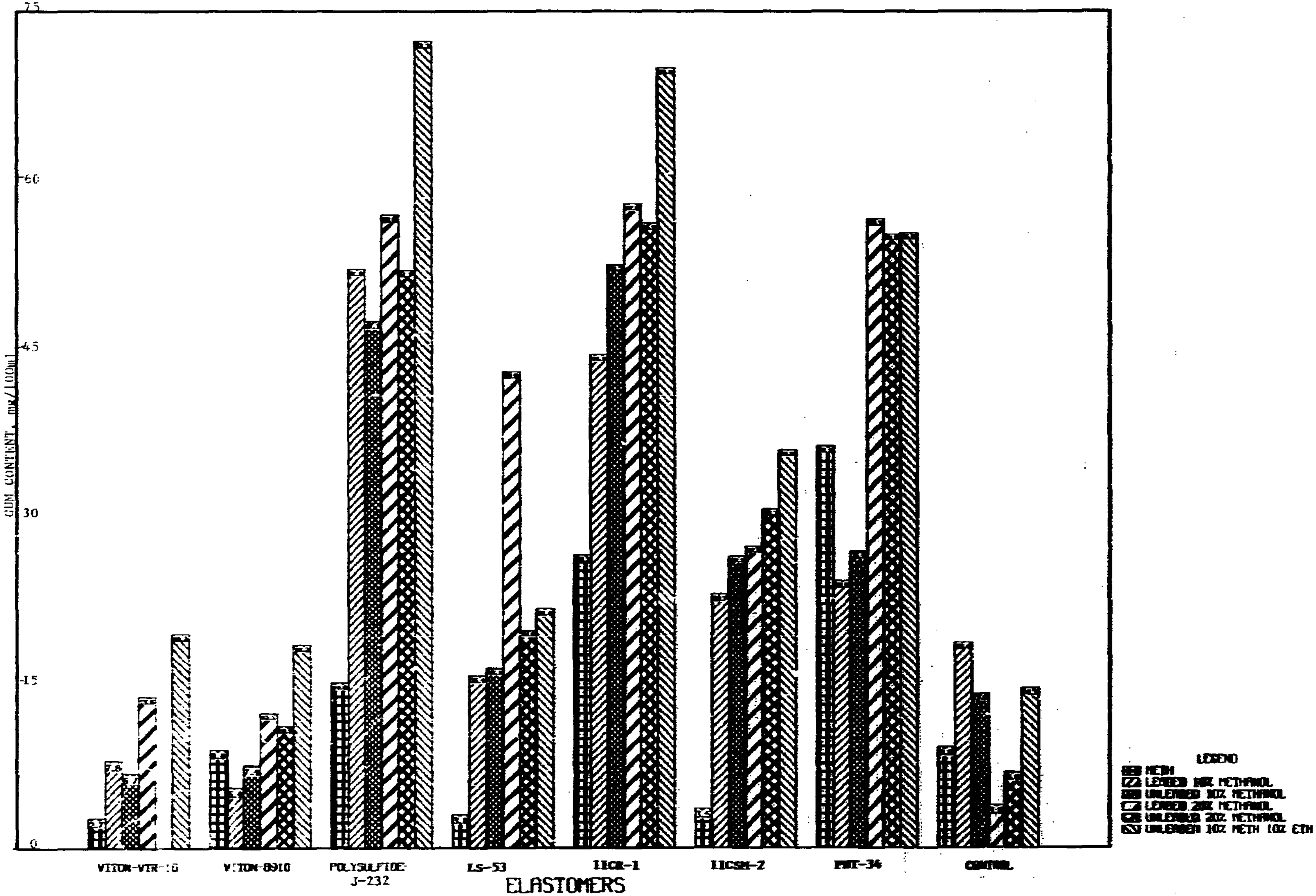

Figure 27. Unwashed gum content of test fuels conditioned with elastomers.

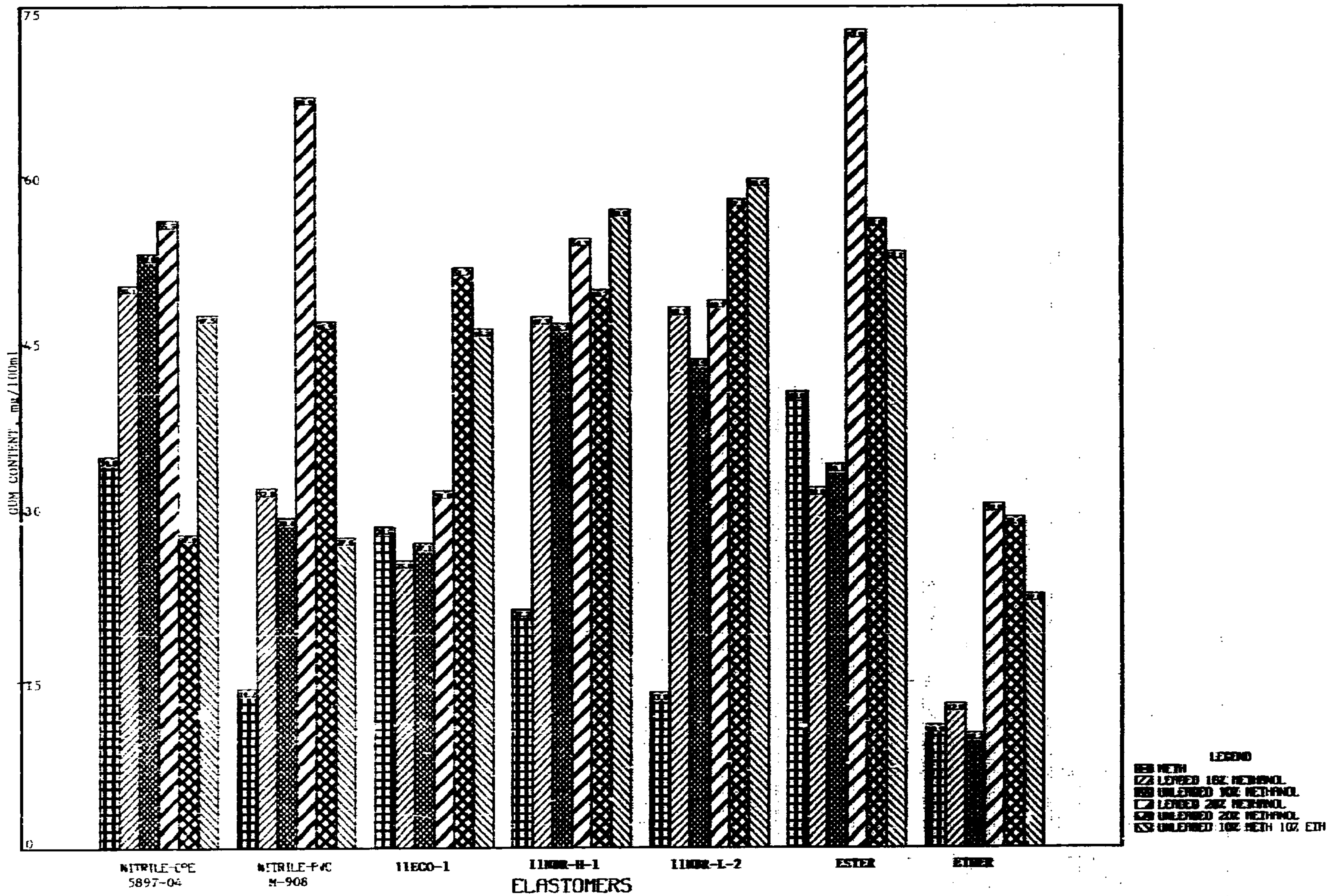

Figure 28. Unwashed gum content of test fuels conditioned with elastomers.

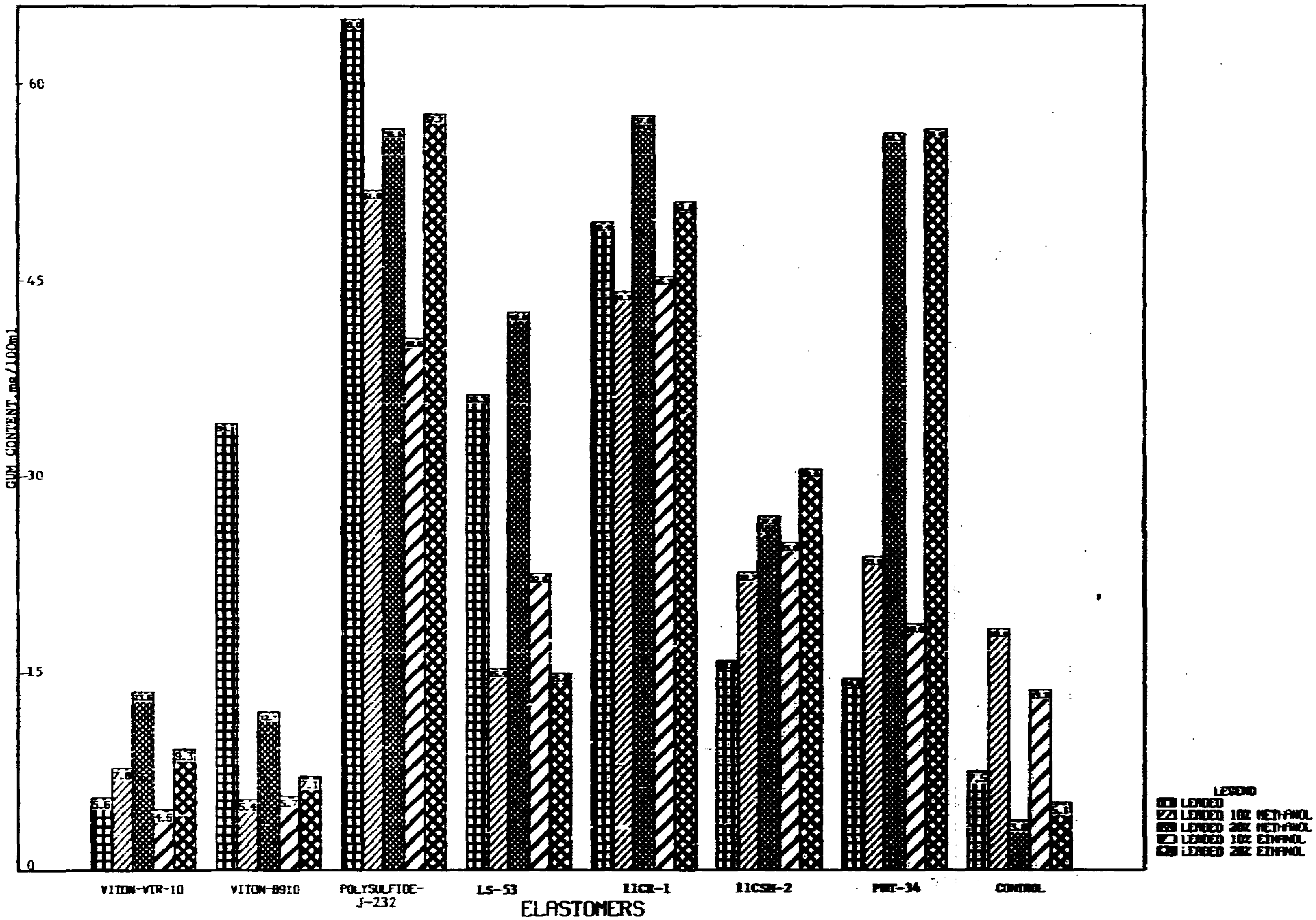

Figure 29. Unwashed gum content of test fuels conditioned with elastomers.

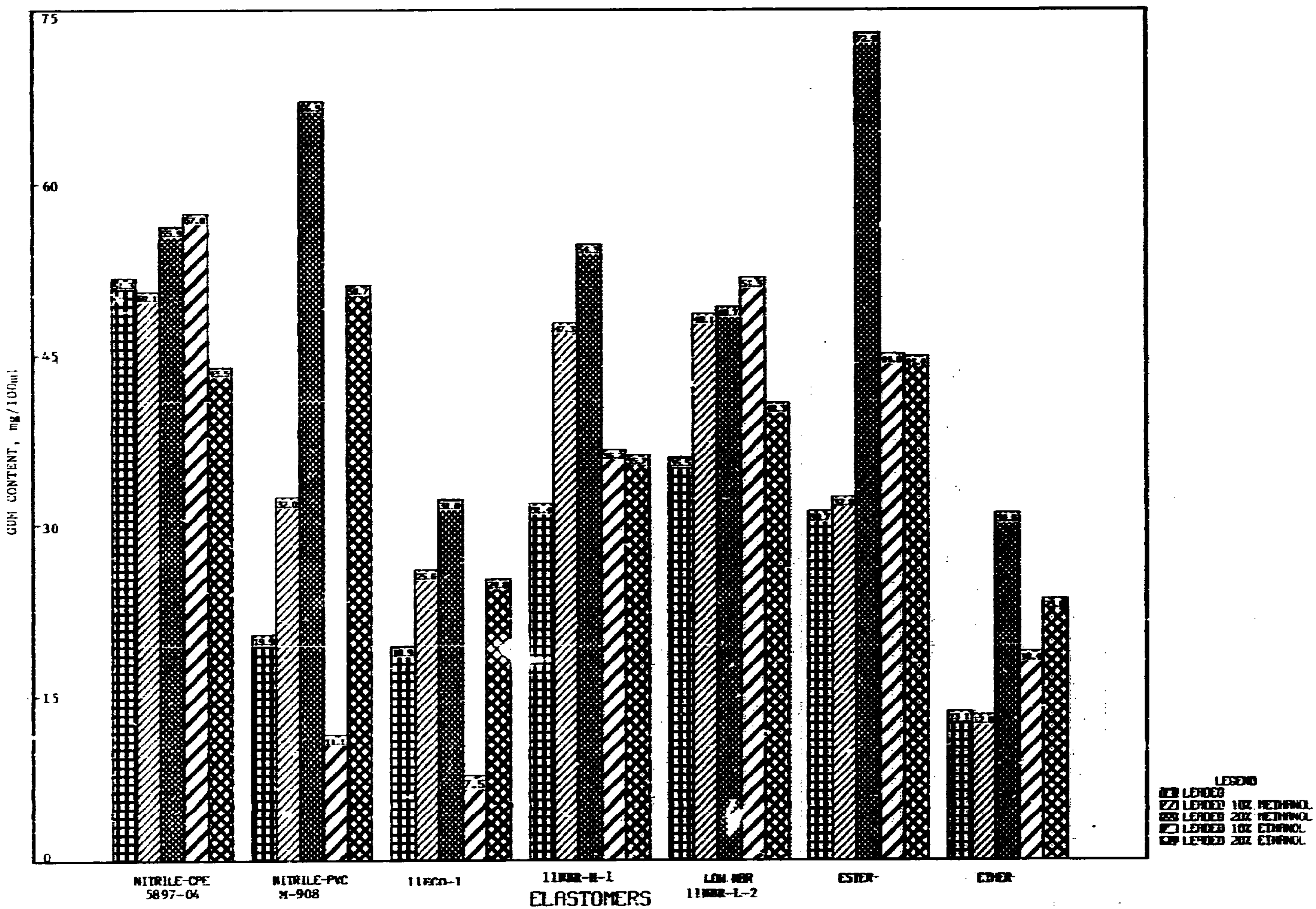

Figure 30. Unwashed gum content of test fuels conditioned with elastomers.

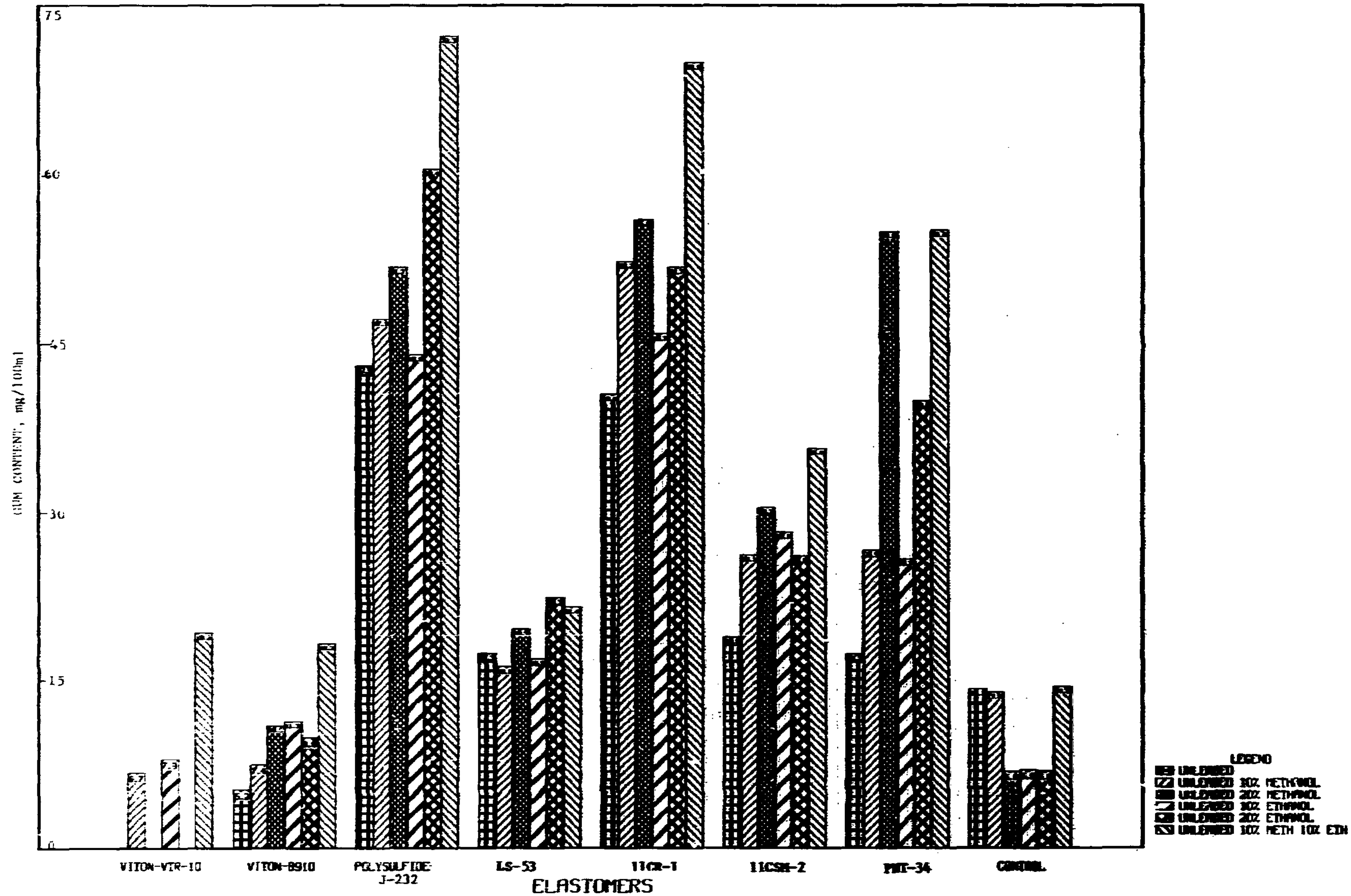

Figure 31. Unwashed gum content of test fuels conditioned with elastomers.

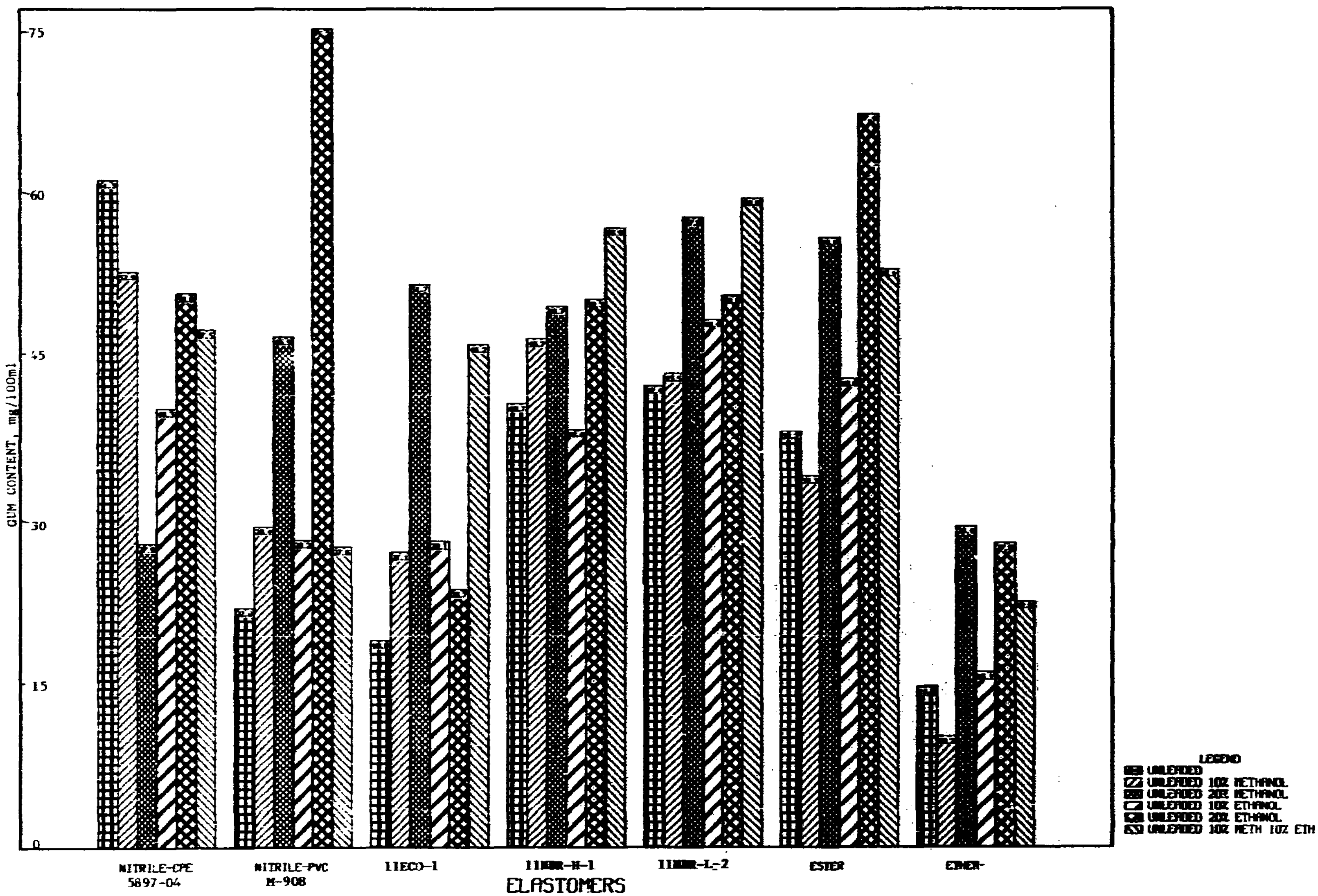

Figure 32. Unwashed gum content of test fuels conditioned with elastomers.

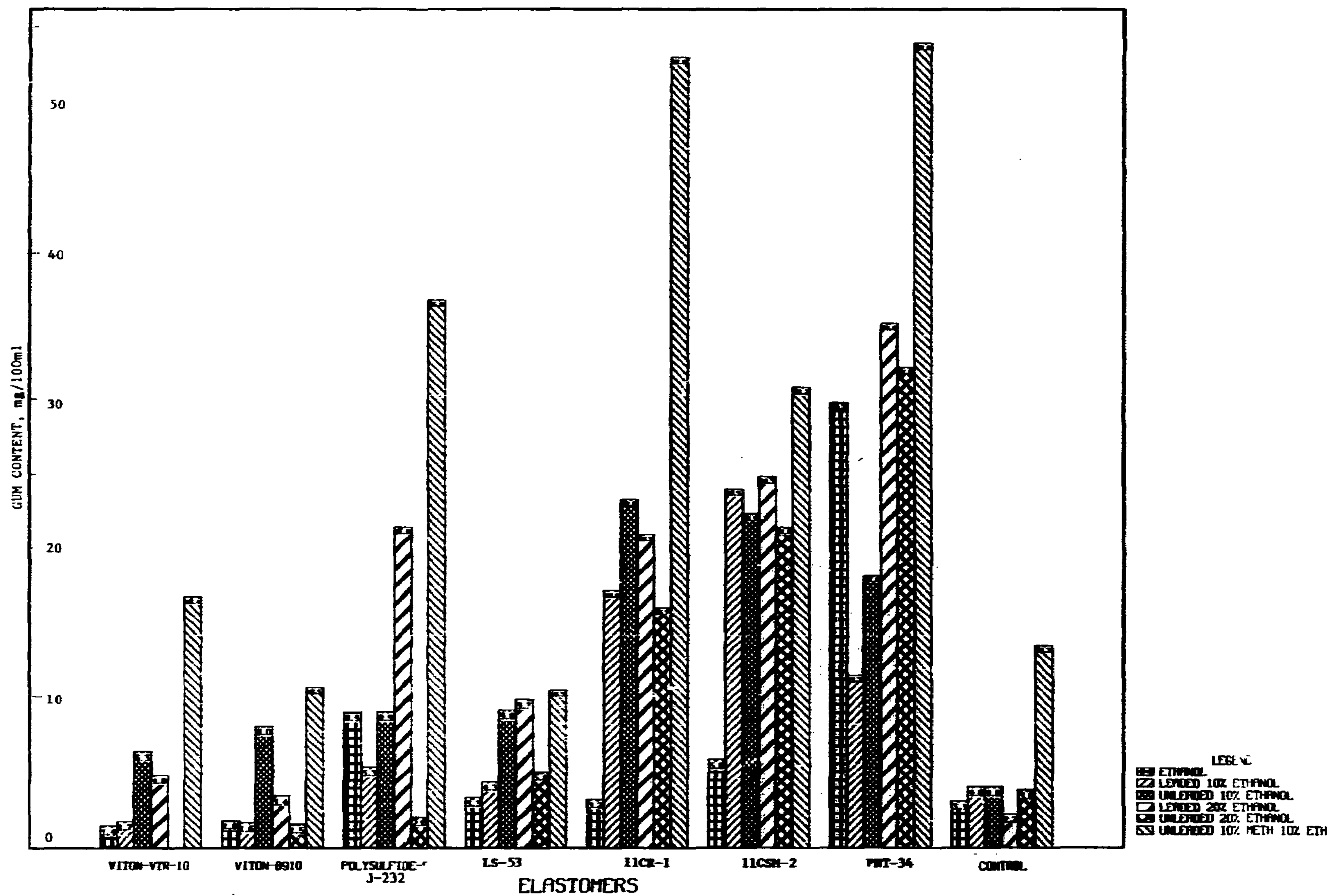

Figure 33. Washed gum content of test fuels conditioned with elastomers.

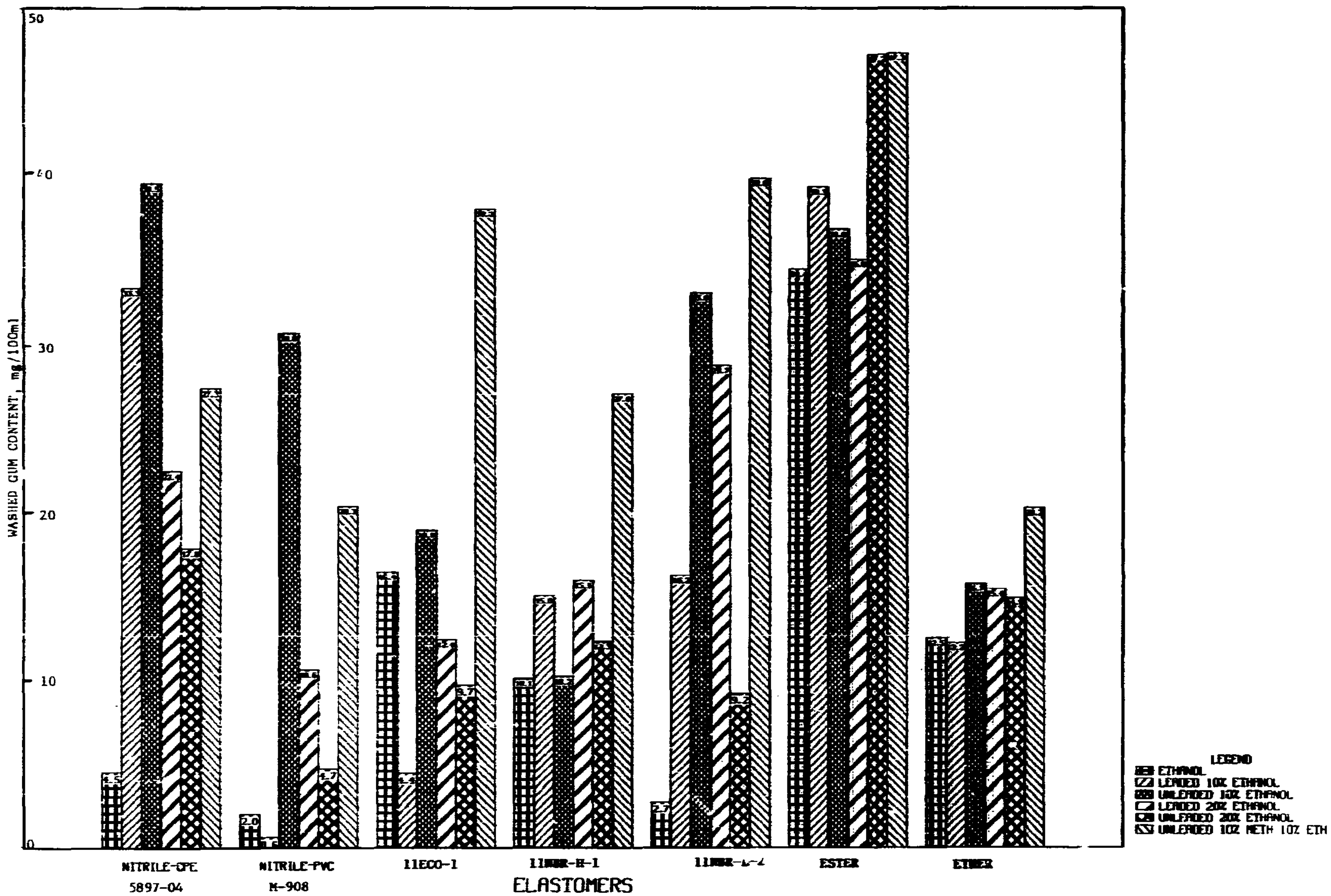

Figure 34. Washed gum content of test fuels conditioned with elastomers.

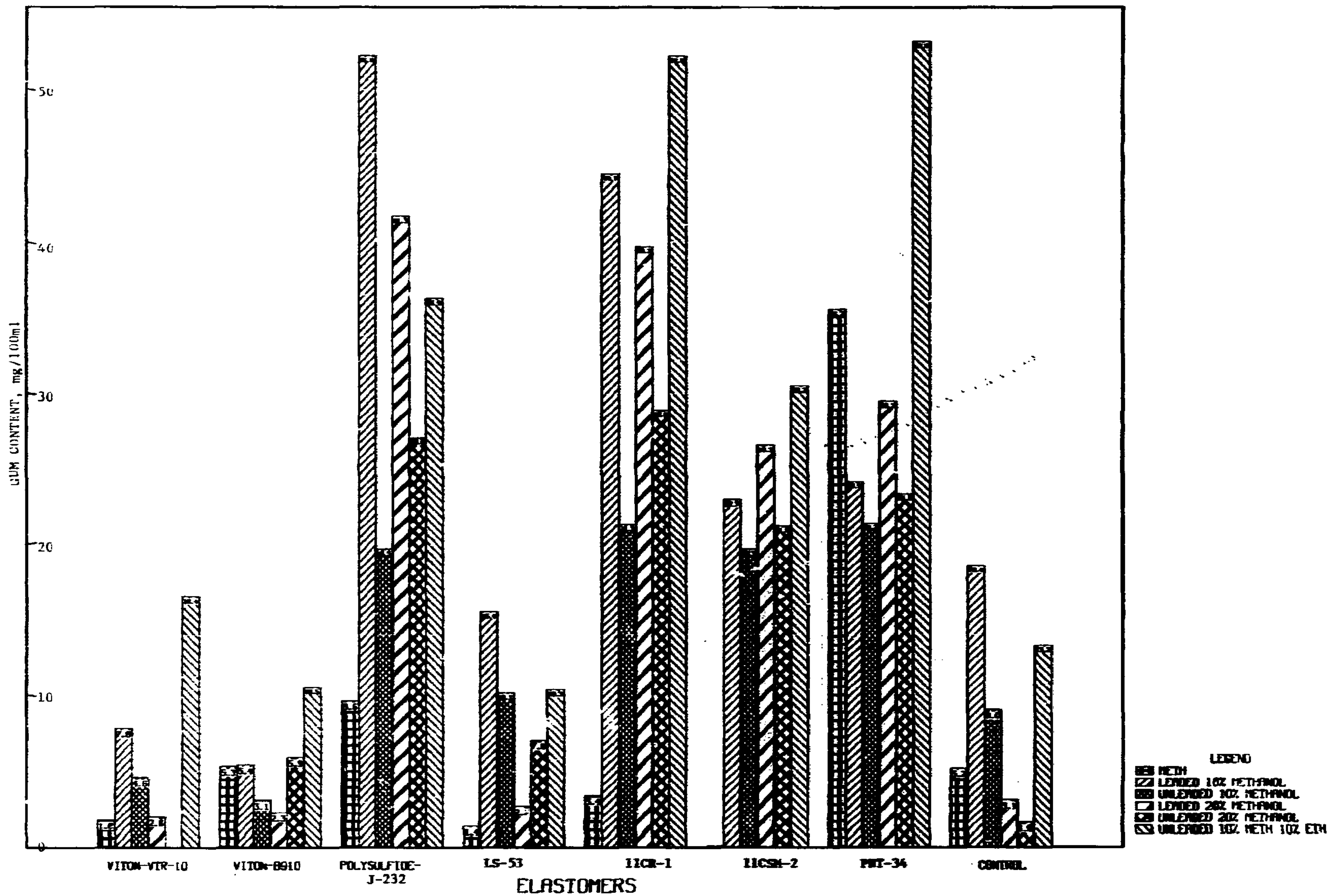

Figure 35. Washed gum content of test fuels conditioned with elastomers.

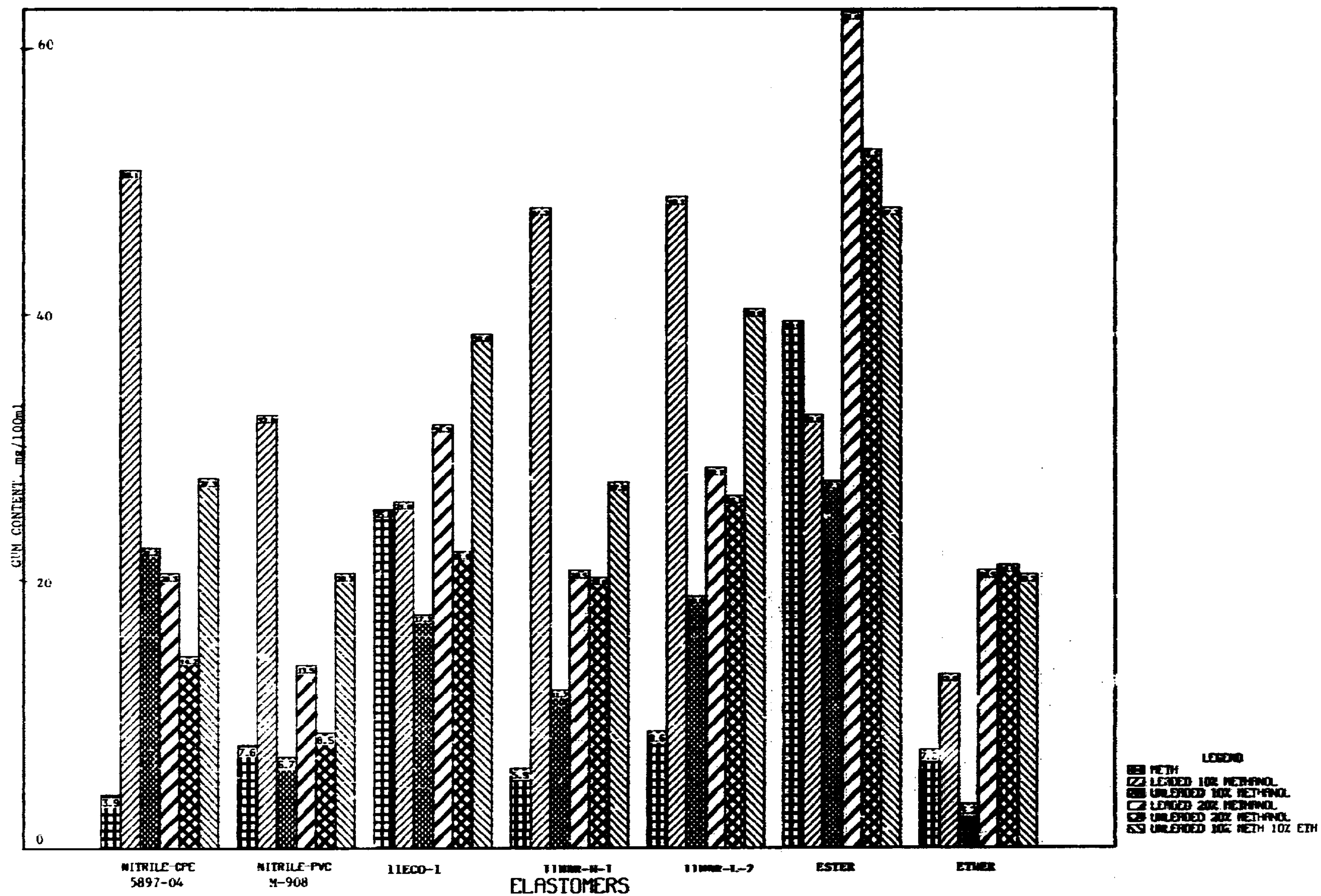

Figure 36. Washed gum content of test fuels conditioned with elastomers.

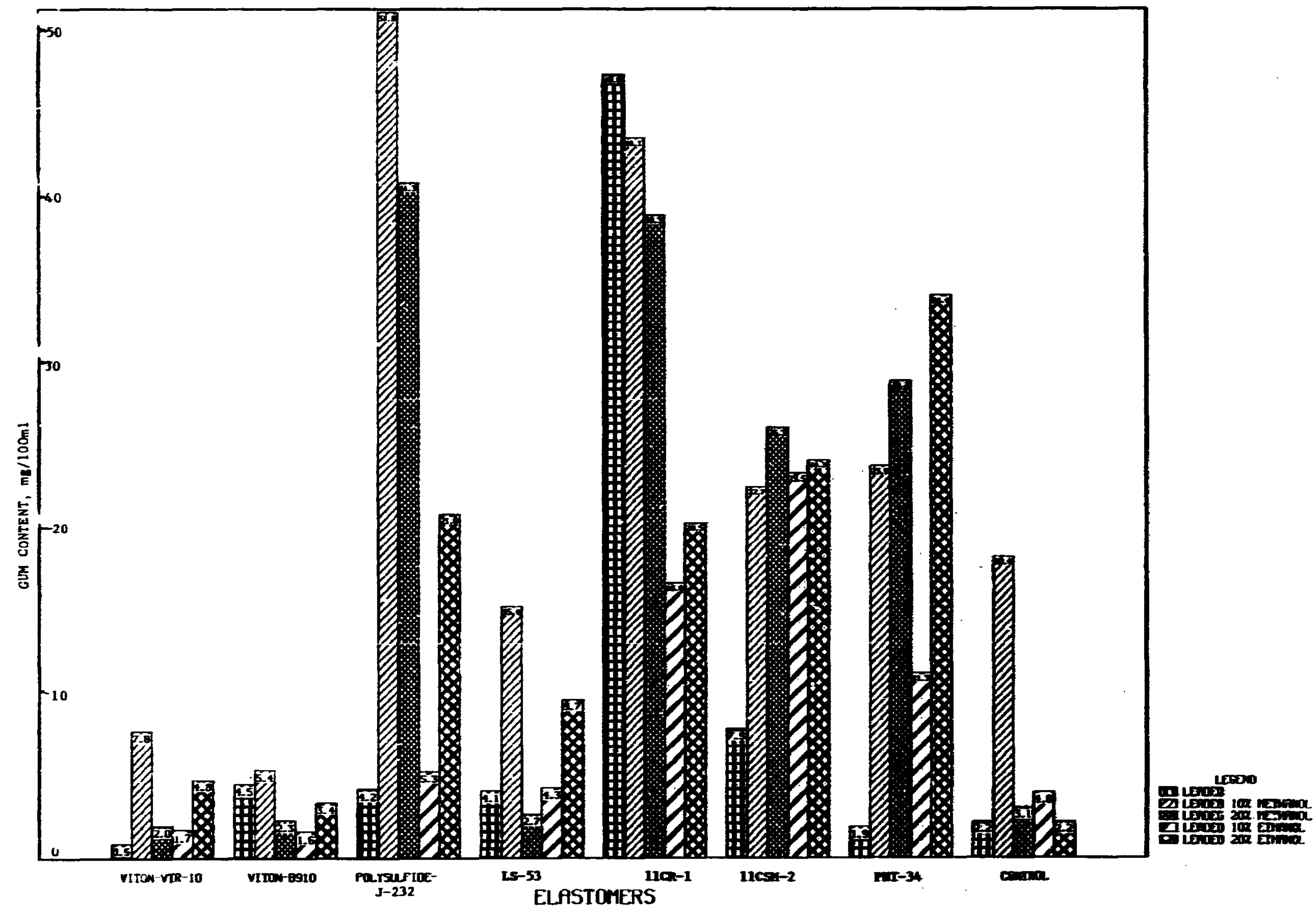

Figure 37. Washed gum content of test fuels conditioned with elastomers.

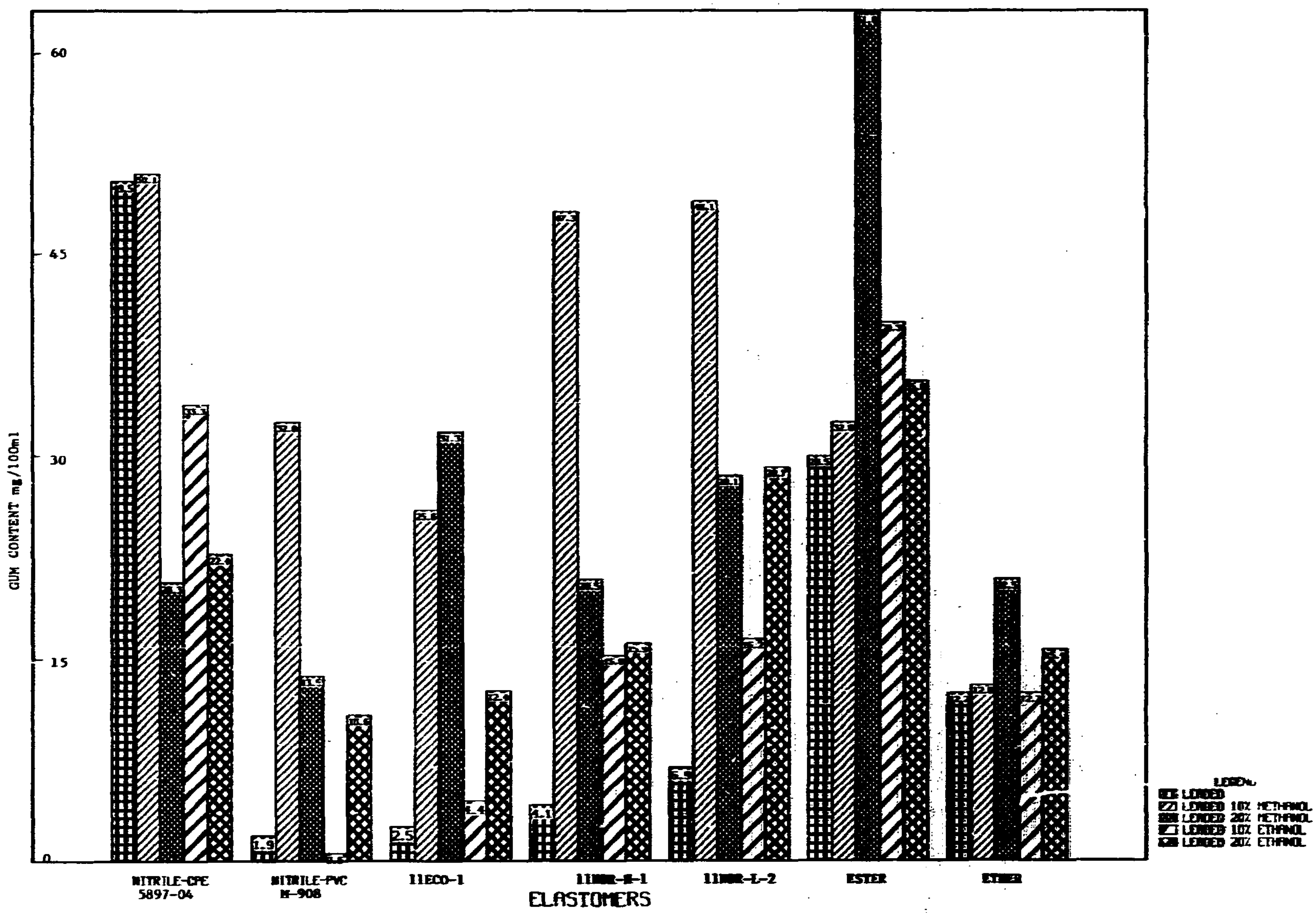

Figure 38. Washed gum content of test fuels conditioned with elastomers.

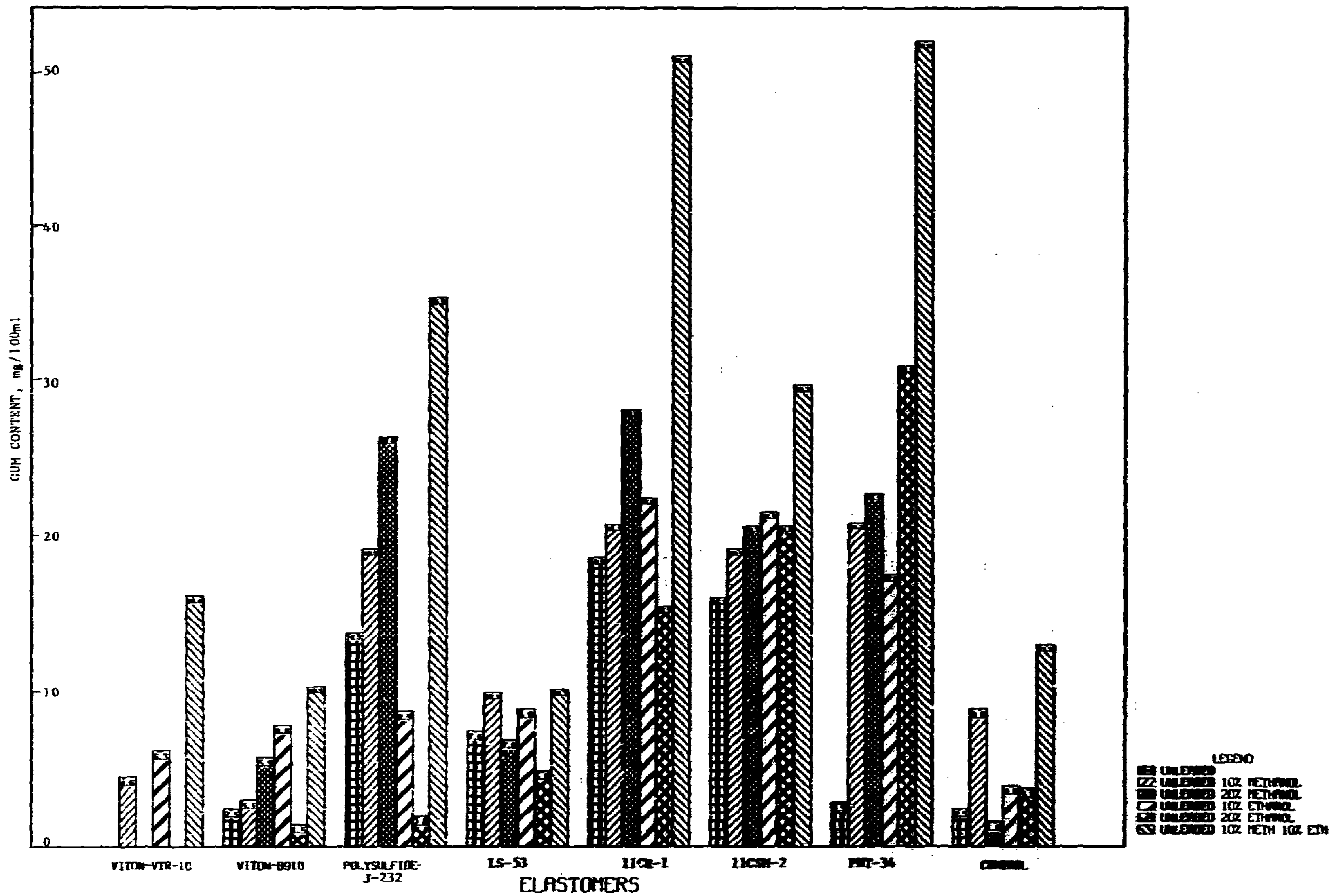

Figure 39. Washed gum content of test fuels conditioned with elastomers.

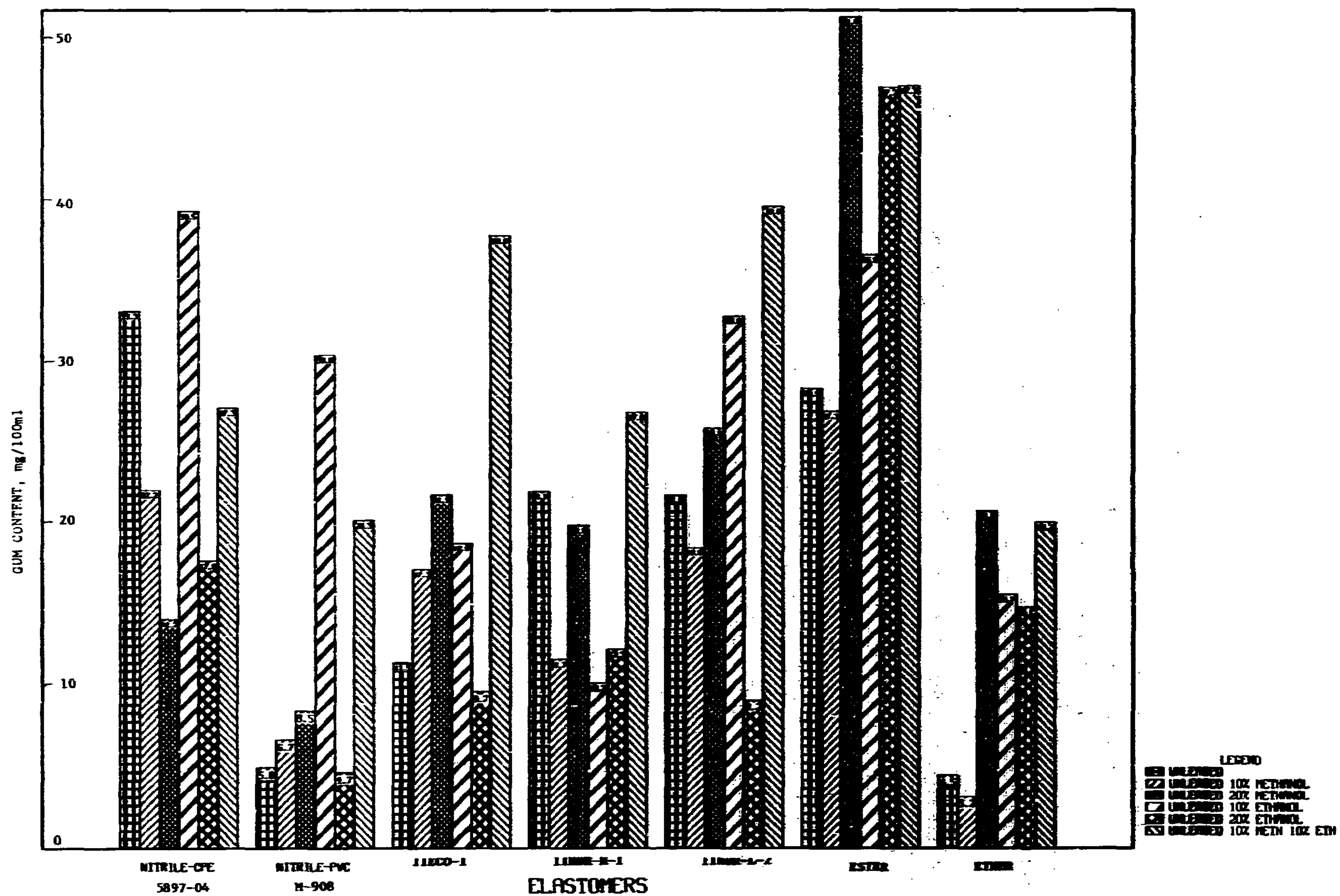

Figure 40. Washed gum content of test fuels conditioned with elastomers.

Since the nitrile/CPE and nitrile/PVC materials were obtained off-the-shelf, their exact formulations are not known. Otherwise, compounds used in this work were purposely prepared with no plasticizer content to preclude introduction of factors which could complicate data analysis. Current elastomeric end item specifications, covering for example, coated fabric tanks or hose, dictate limits such as 20 mg/100 ml for unwashed gum and 6 mg/100 ml for washed gum. These values are more realistic in that surface area contact would not be as great in end-item applications as was encountered with the powdered samples in this work. It is obvious that blended fuels can significantly alter fuel gum content contributions by elastomers. Therefore, fuel/elastomer compatibility must be closely monitored as must proper compound selection and specification, to achieve optimum system performance.

(2) **Plastics.** Since no definite criteria exist for establishing plastic/fuel compatibility, a level of 10 mg/100 ml was arbitrarily chosen as the point delineating negligible or significant effects of plastics on unwashed and washed gum content. In the case of unwashed gums, (see Figures 41 through 44) the following combinations produced values exceeding that limit: polyproylene—in all cases except the base leaded fuel, pure alcohols, leaded/10 percent ethanol and the unleaded 10/10 blend; nylon 6/6 in leaded/20 percent methanol; nylon 6/12 in methanol, leaded/10 percent methanol and both leaded/ethanols; phenolic in methanol and all methanol blends and leaded/20 percent ethanol; PBT in the leaded/ethanols. The most significant increase was noted for nylon 6/12, polypropylene and phenolic in leaded/10 percent methanol. The only fuel/plastic combinations which displayed significantly high washed gum values (see Figures 45 through 48) were: nylon 6/12 in leaded/10 percent methanol and 20 percent ethanol; polypropylene in leaded/10 percent methanol and unleaded/20 percent ethanol; and phenolic in pure methanol and leaded/10 percent methanol. Again, these three plastics were mostly affected by exposures to the leaded/10 percent methanol blend. These results demonstrate that plastics generally have a much less significant effect on fuel contamination, but isolated severe cases can occur and compatibility should be verified before using.

(3) **Metals.** Assuming the same guidelines for metals as were used for plastics, metal/fuel combinations displaying most significant unwashed gum changes (see Figure 49 through 52) were brass in unleaded/10 percent methanol, ethanol and the 10/10 mixture, brass in leaded/10 percent methanol and zinc in unleaded/10 percent methanol. When the washed gum determination (see Figures 53 through 56) was conducted, values for the zinc in unleaded/10 percent methanol and the brass in unleaded/10/10 mixture were reduced substantially, while the other noted brass/fuel values remained high. While the other metals—6061 aluminum and carbon steel—did effect some specific instances of increased gum content for blends as opposed to the pure fuels, none was considered of sufficient magnitude to influence end-item performance.

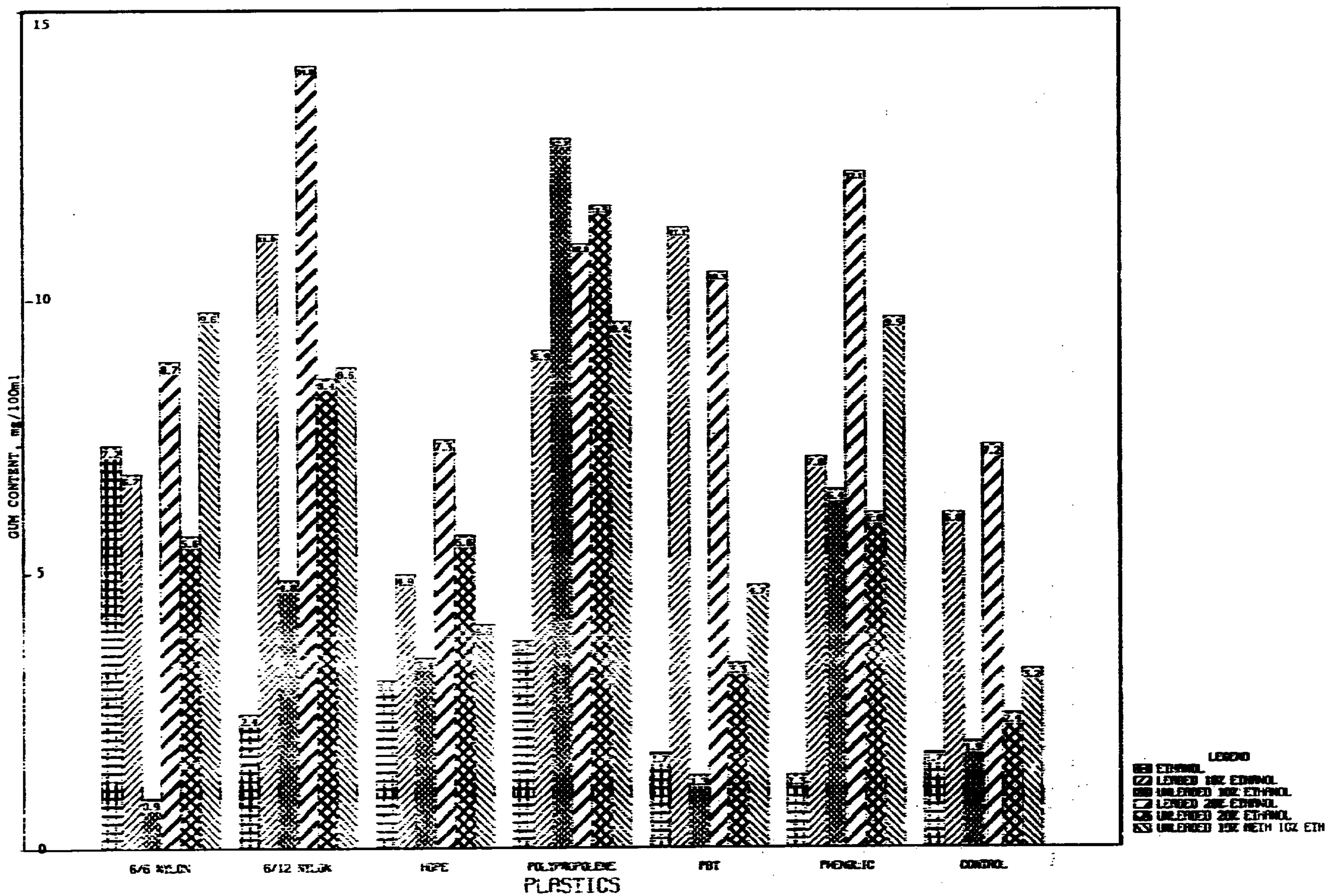

Figure 41. Unwashed gum content of test fuels conditioned with plastics.

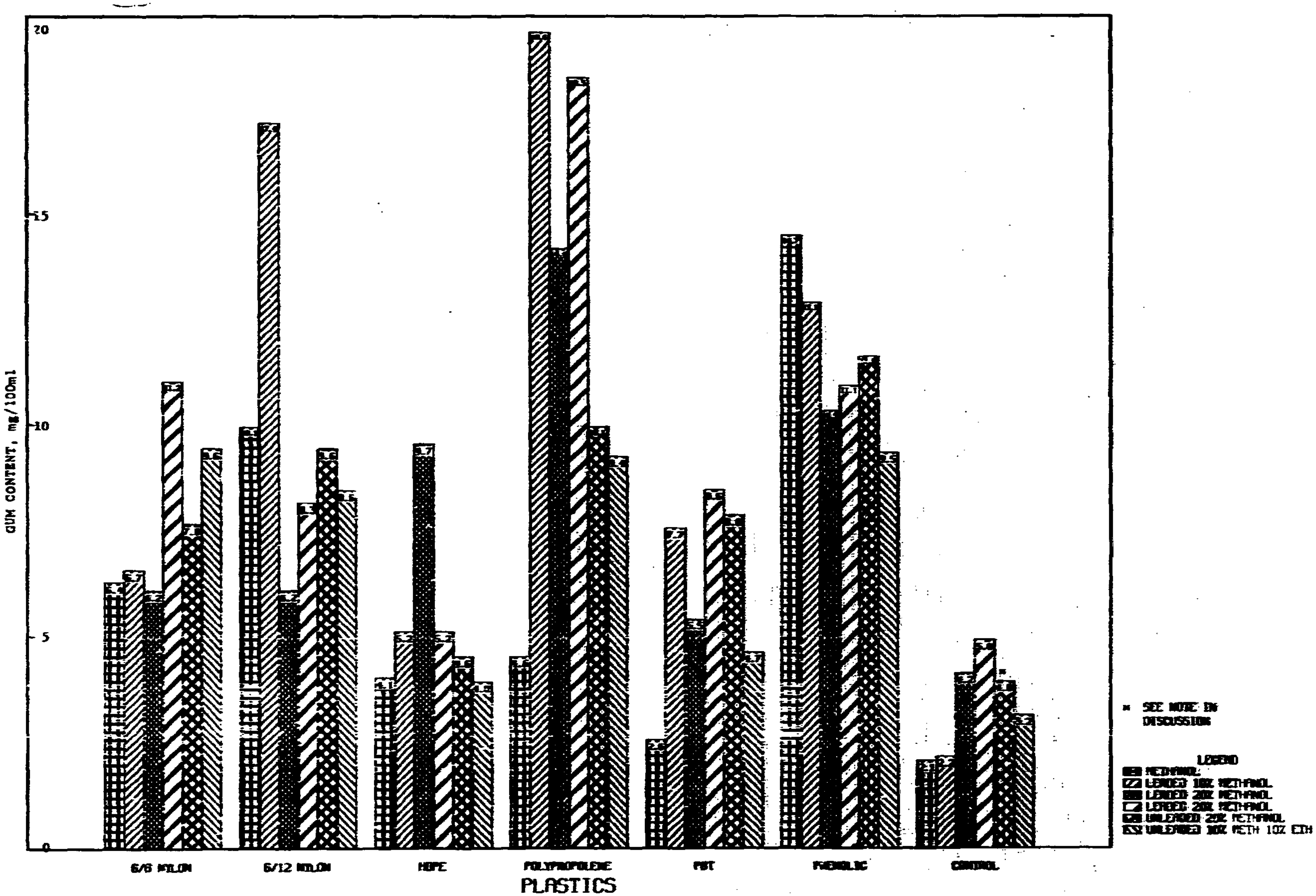

Figure 42. Unwashed gum content of test fuels conditioned with plastics.

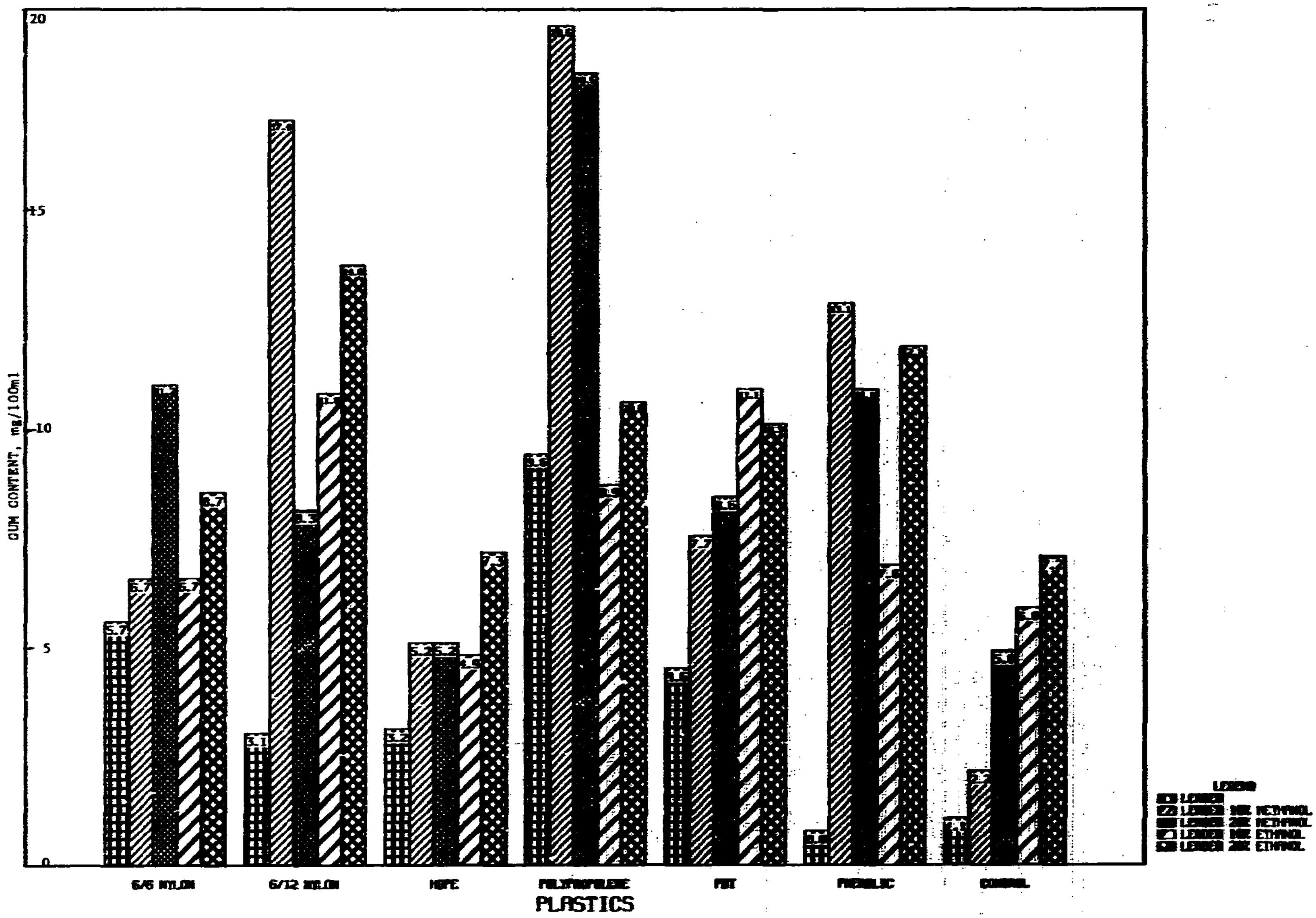

Figure 43. Unwashed gum content of test fuels conditioned with plastics.

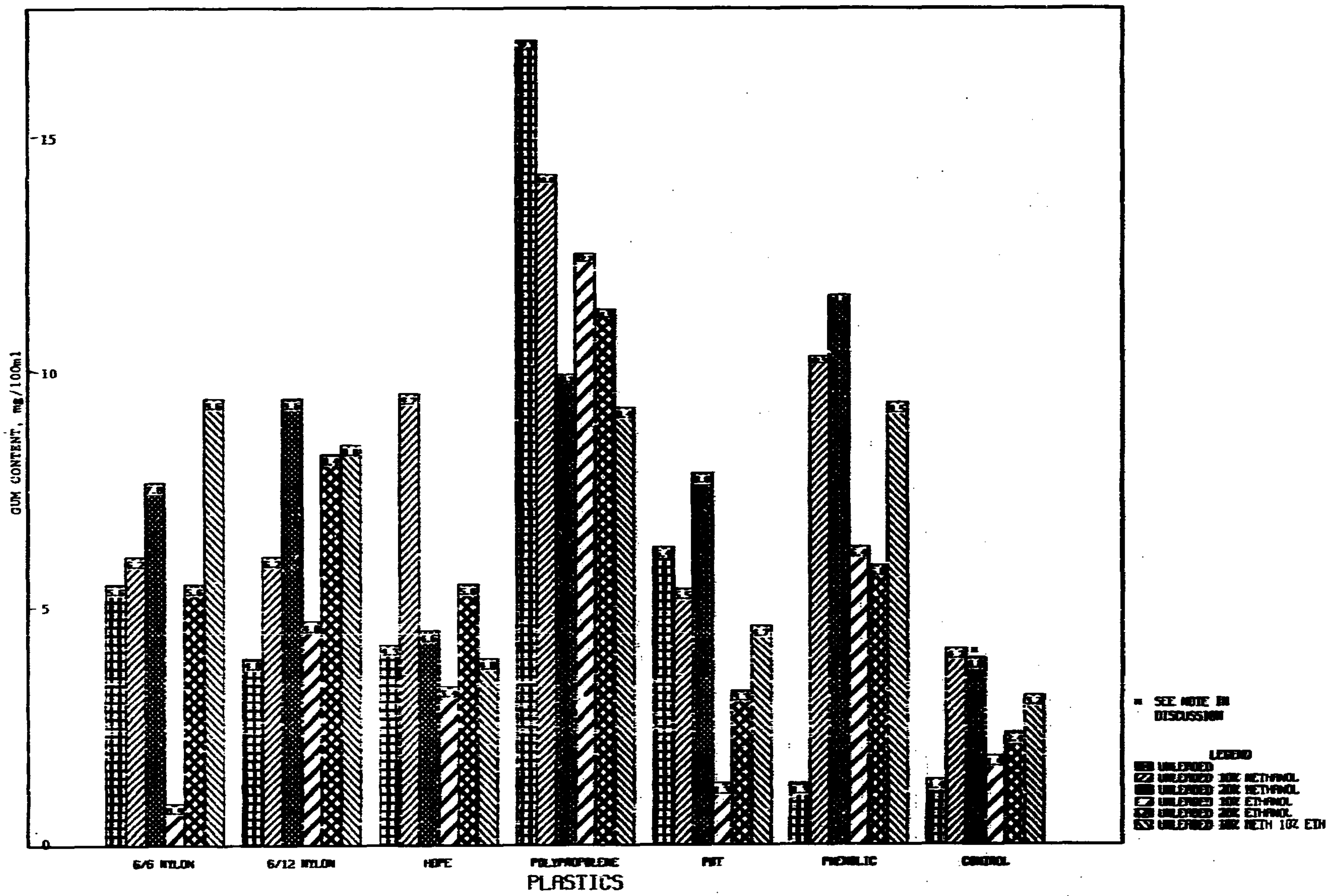

Figure 44. Unwashed gum content of test fuels conditioned with plastics.

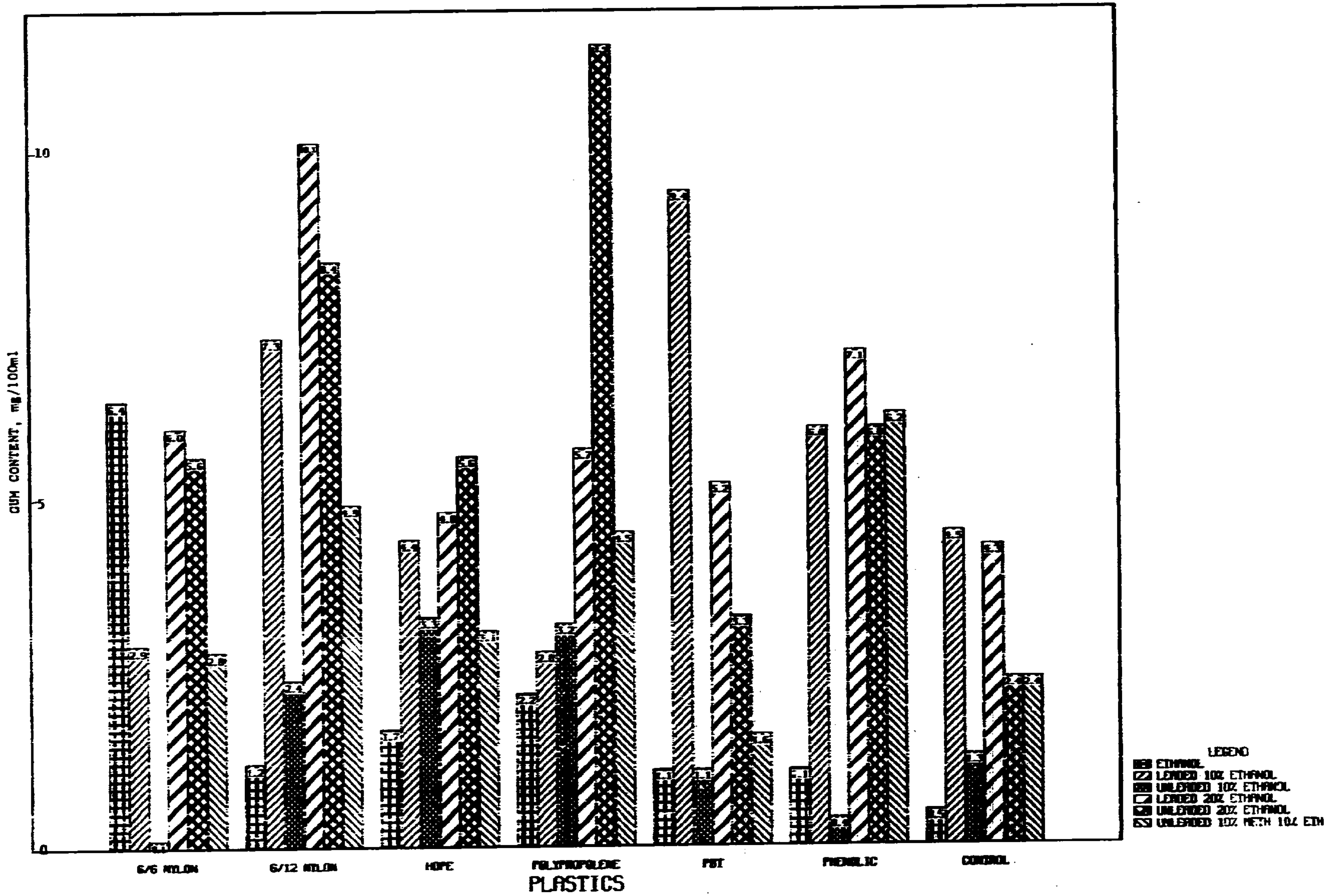

Figure 45. Washed gum content of test fuels conditioned with plastics.

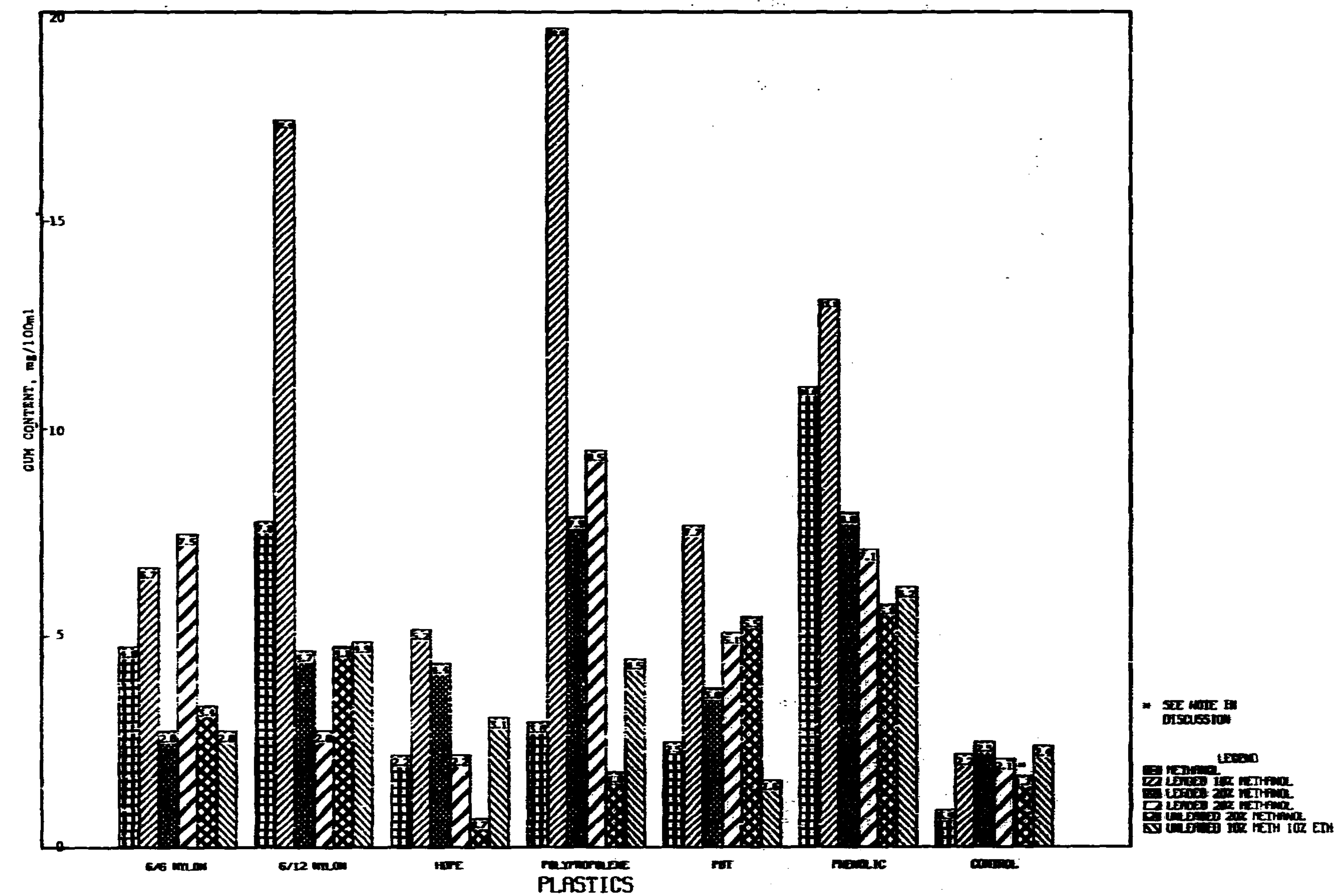

Figure 46. Washed gum content of test fuels conditioned with plastics.

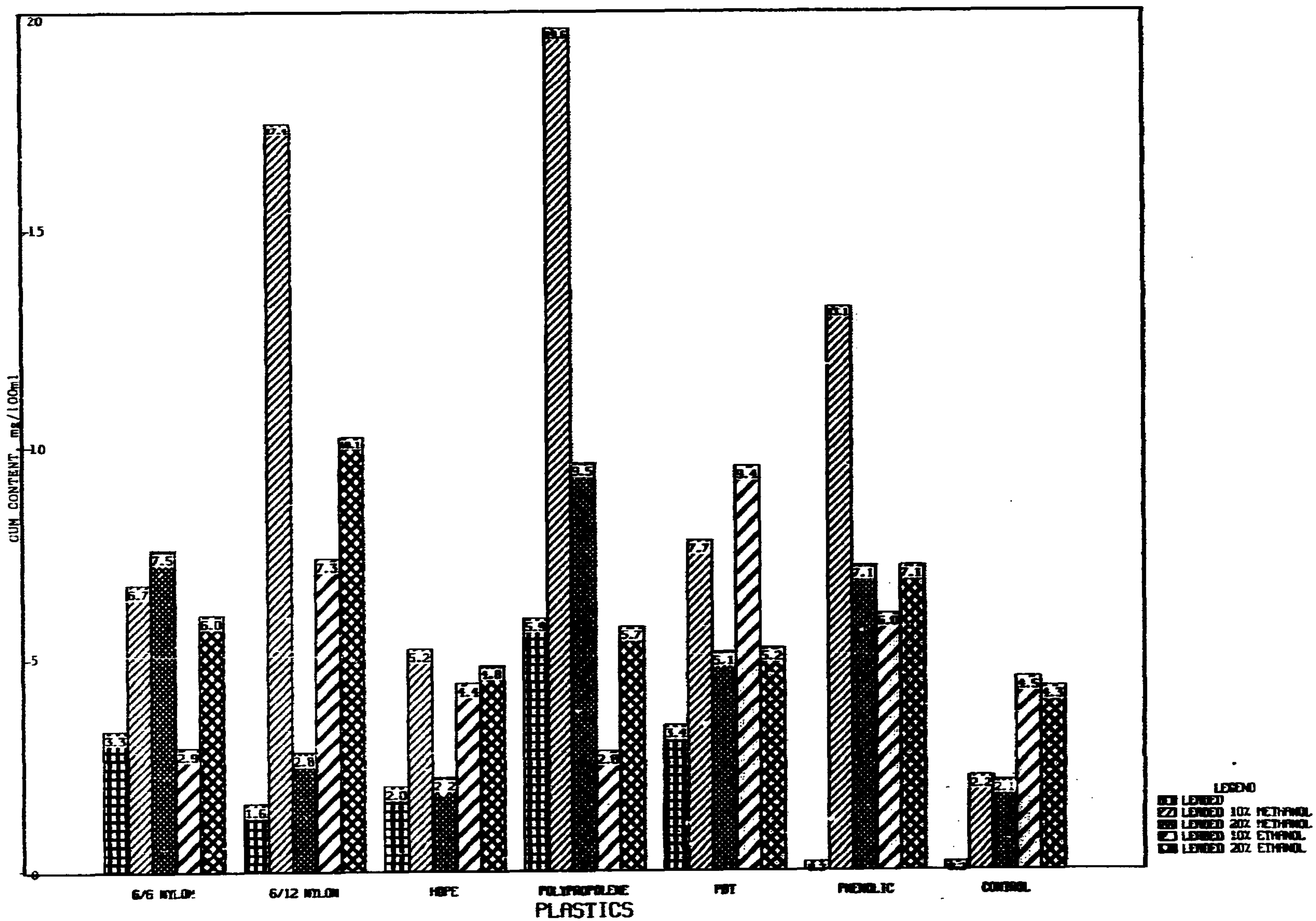

Figure 47. Washed gum content of test fuels conditioned with plastics.

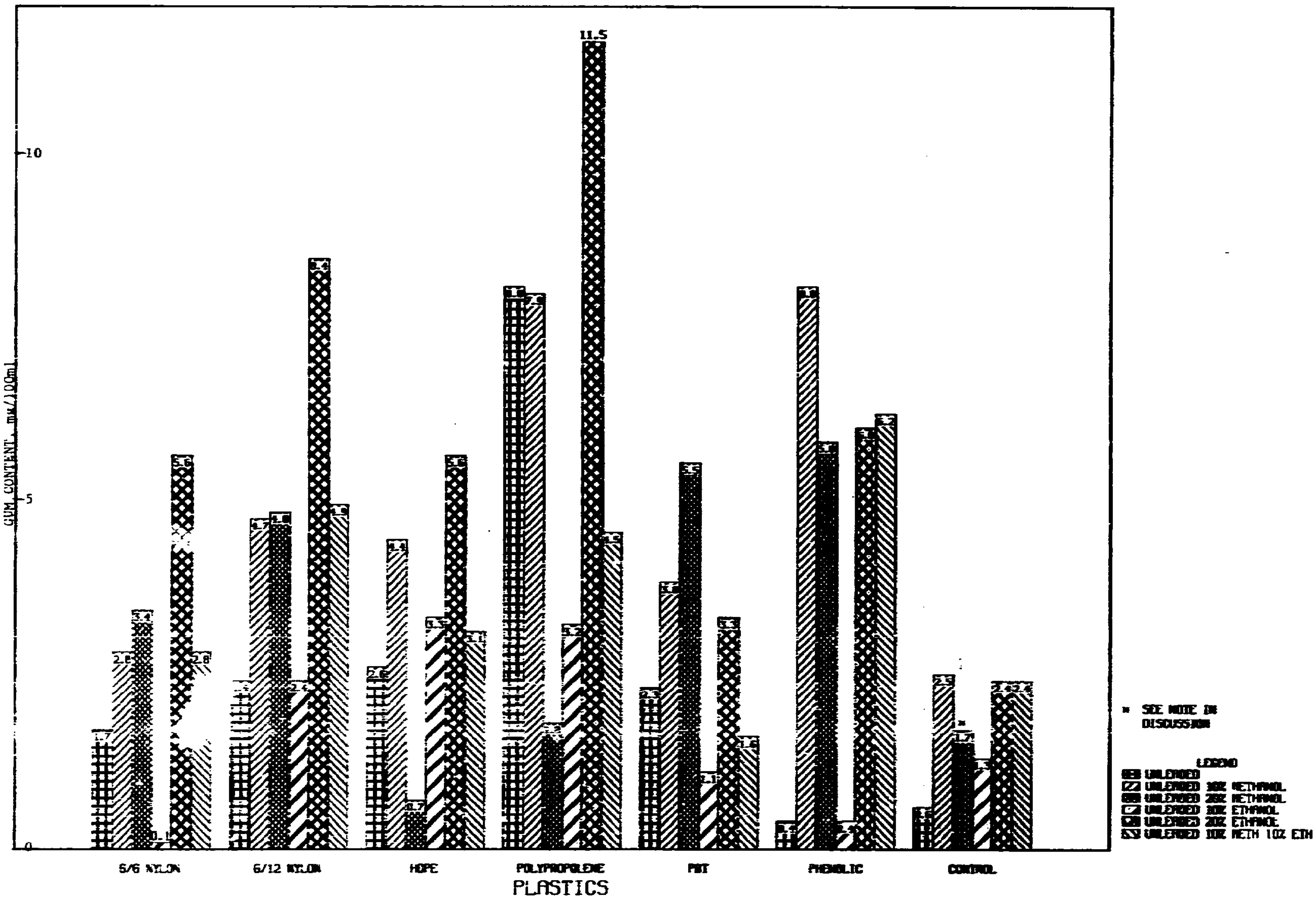

Figure 48. Washed gum content of test fuels conditioned with plastics.

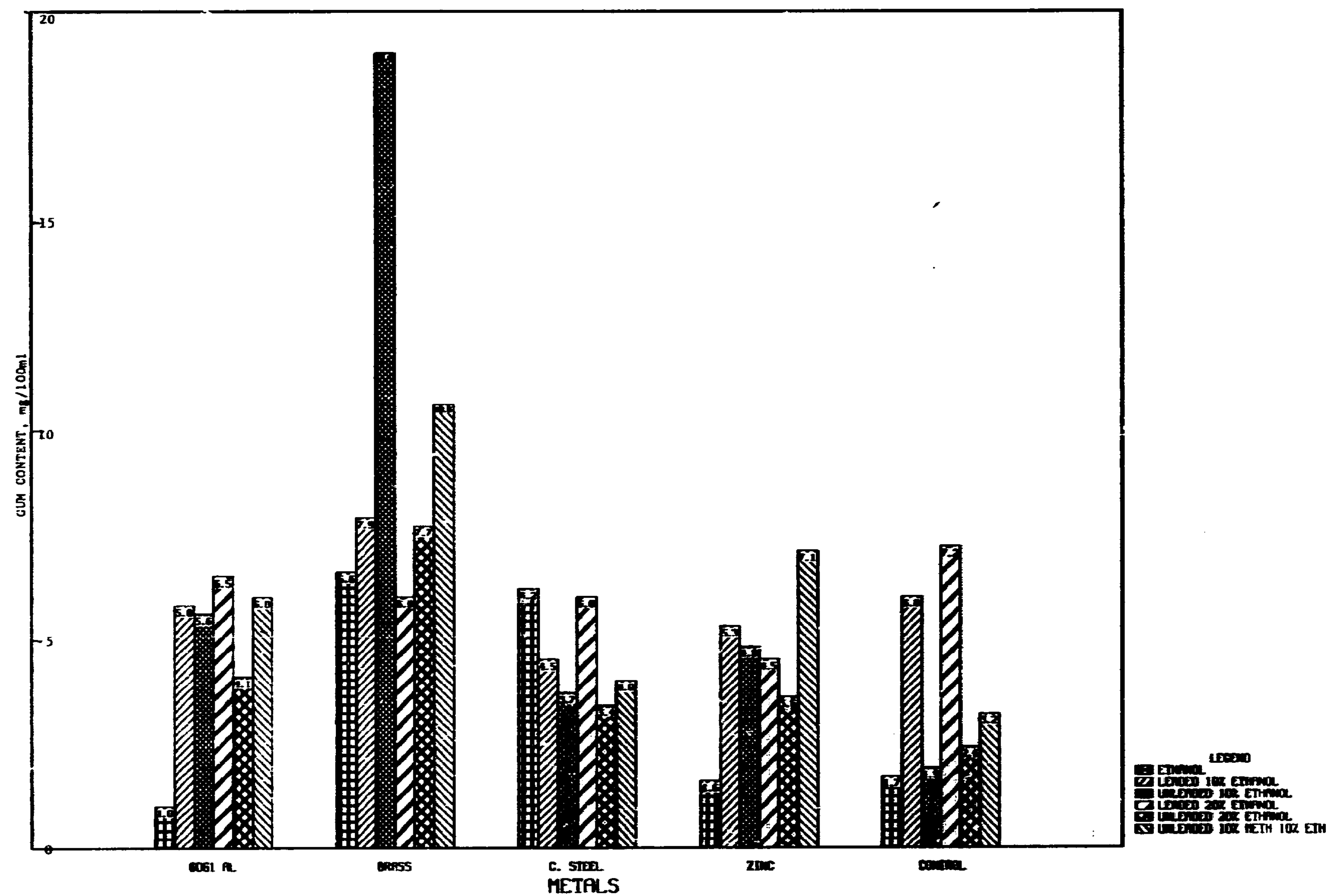

Figure 49. Unwashed gum content of test fuels conditioned with metals.

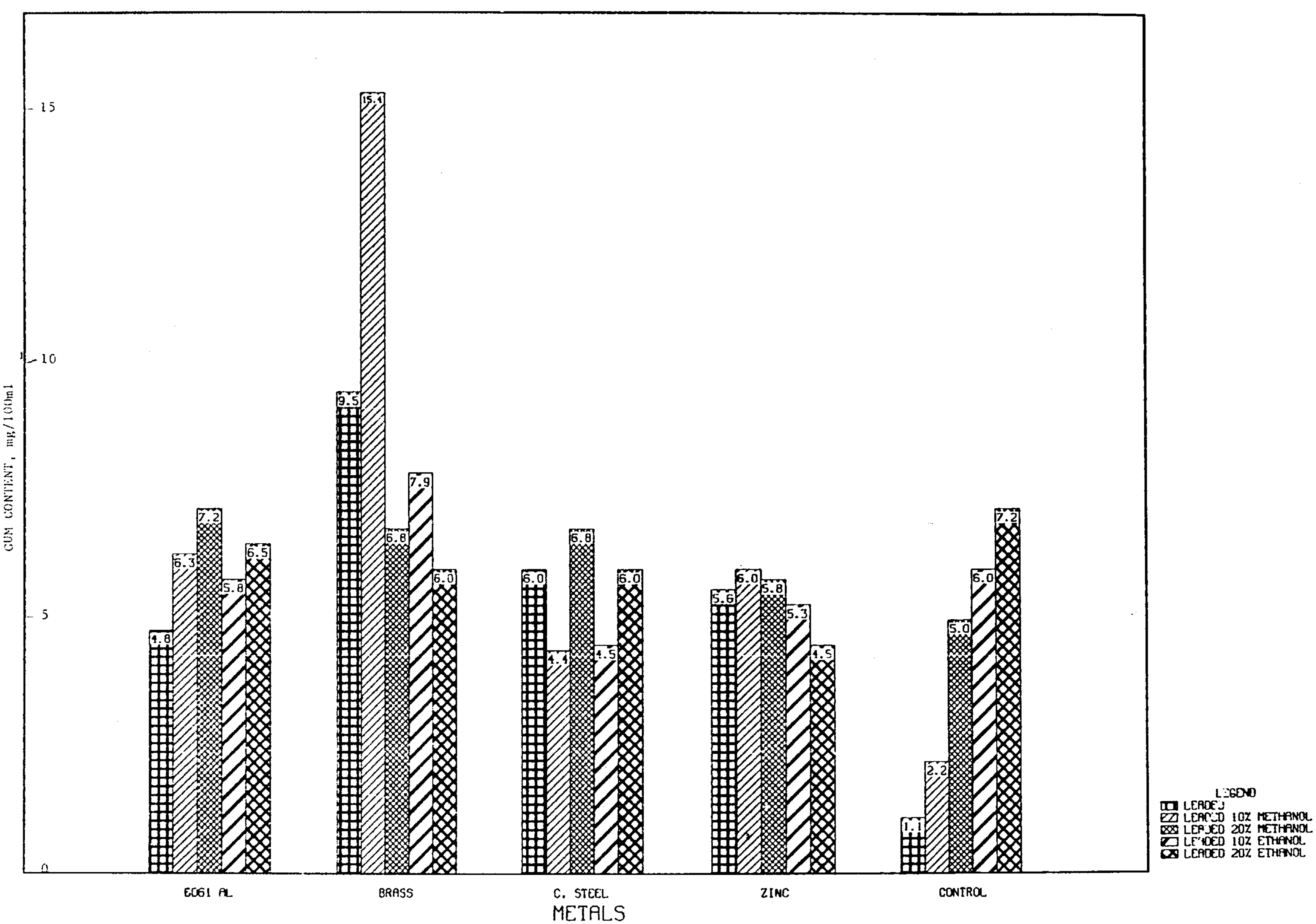

Figure 51. Unwashed gum content of test fuels conditioned with metals.

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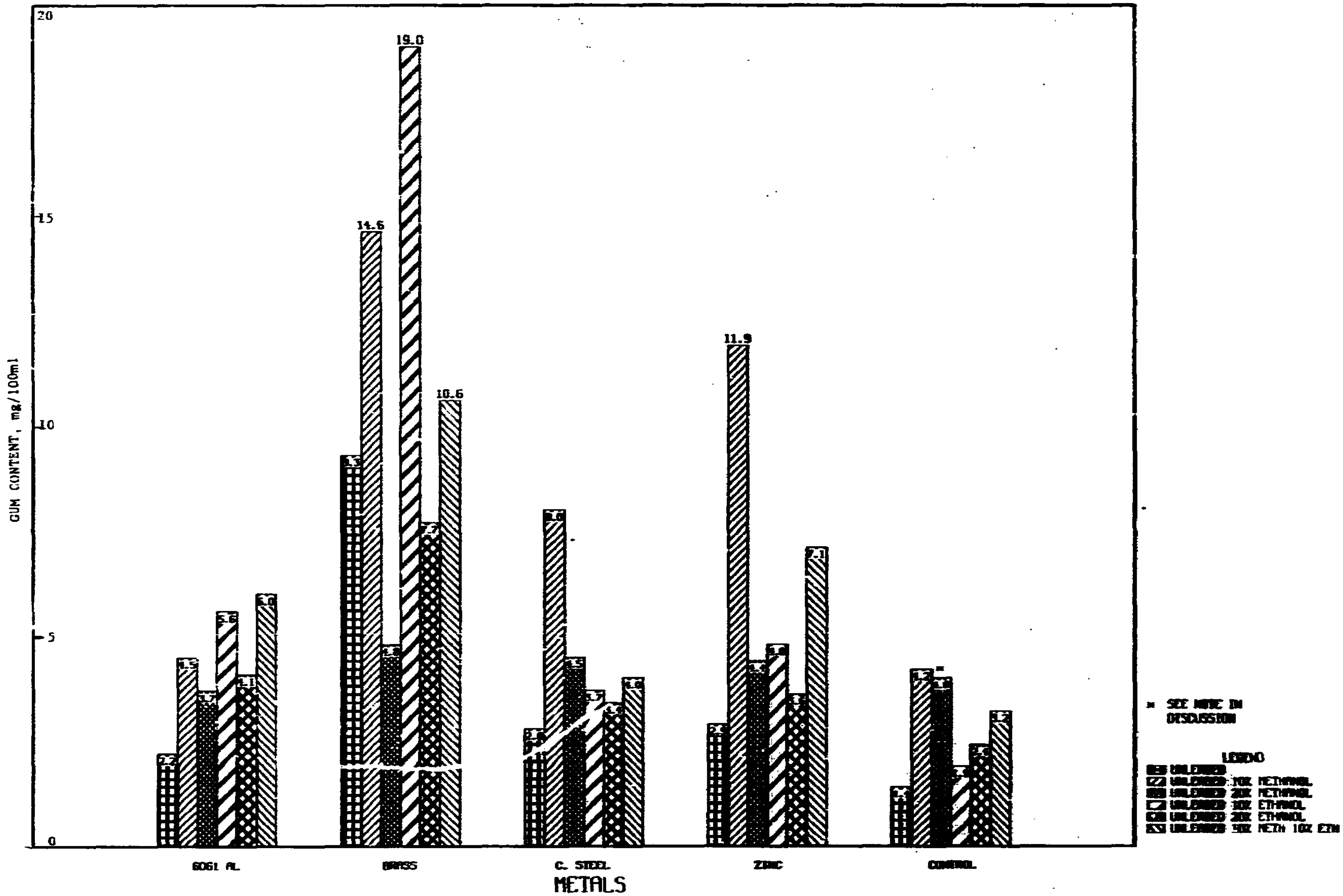

Figure 52. Unwashed gum content of test fuels conditioned with metals.

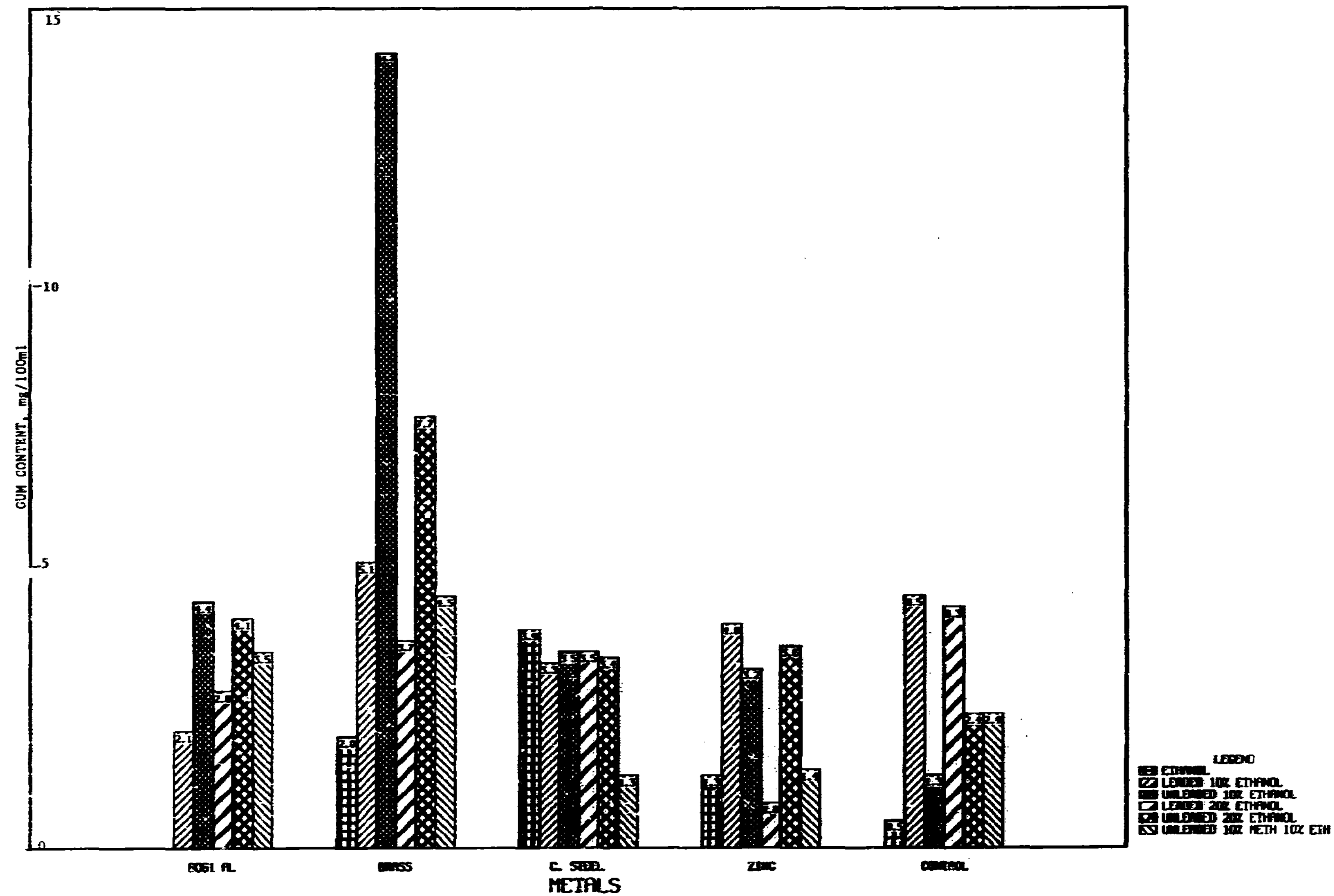

Figure 53. Washed gum content of test fuels conditioned with metals.

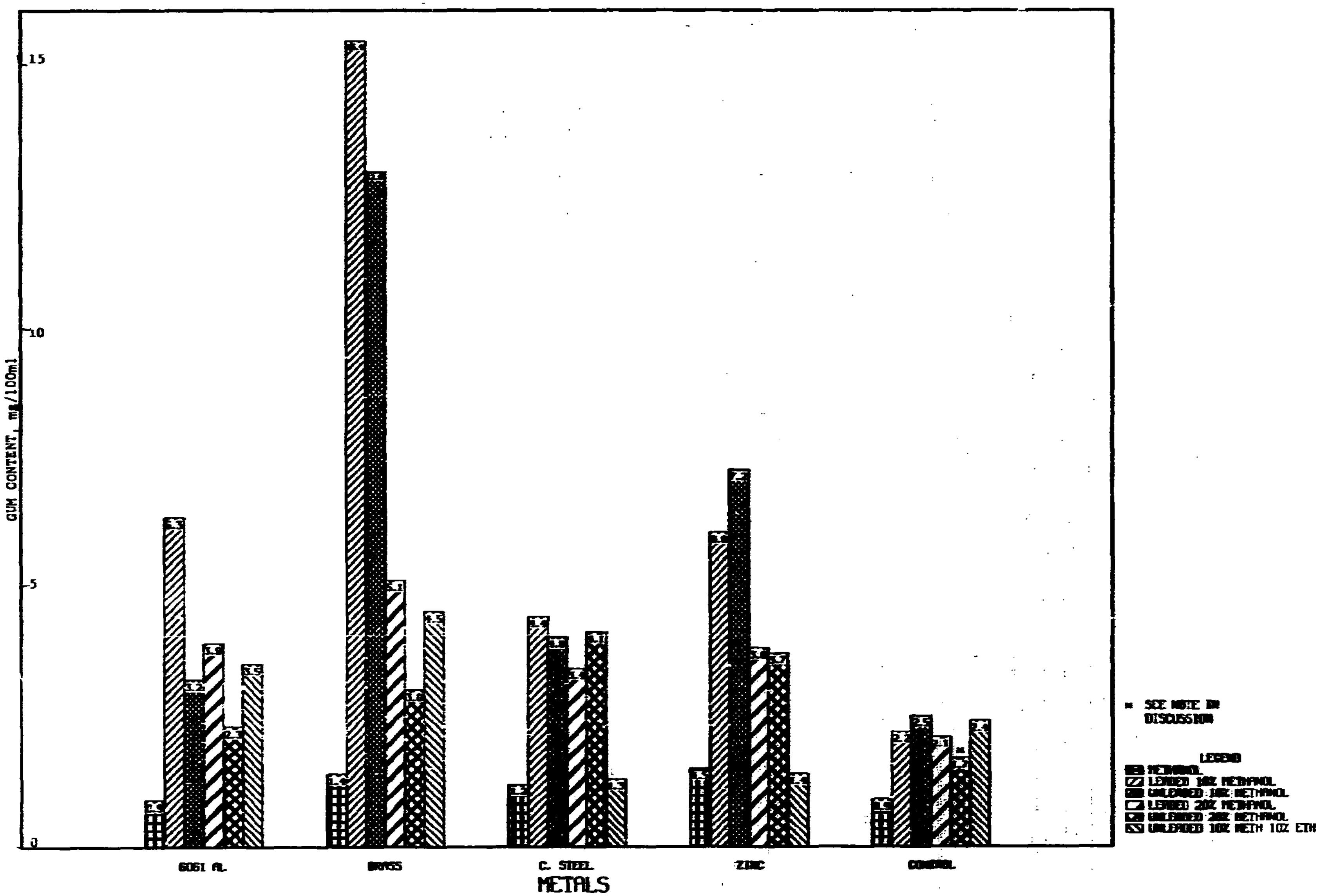

Figure 54. Washed gum content of test fuels conditioned with metals.

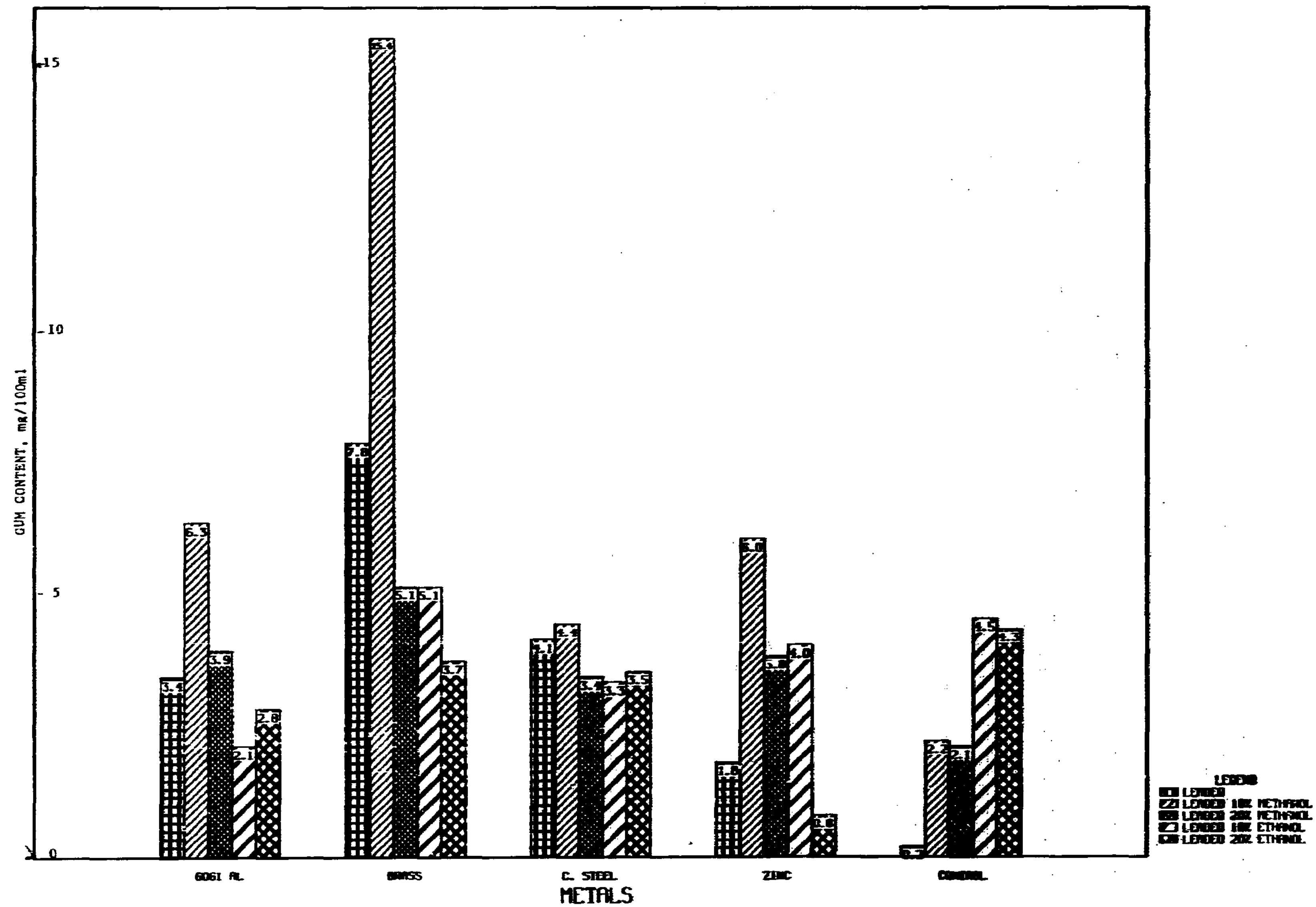

Figure 55. Washed gum content of test fuels conditioned with metals.

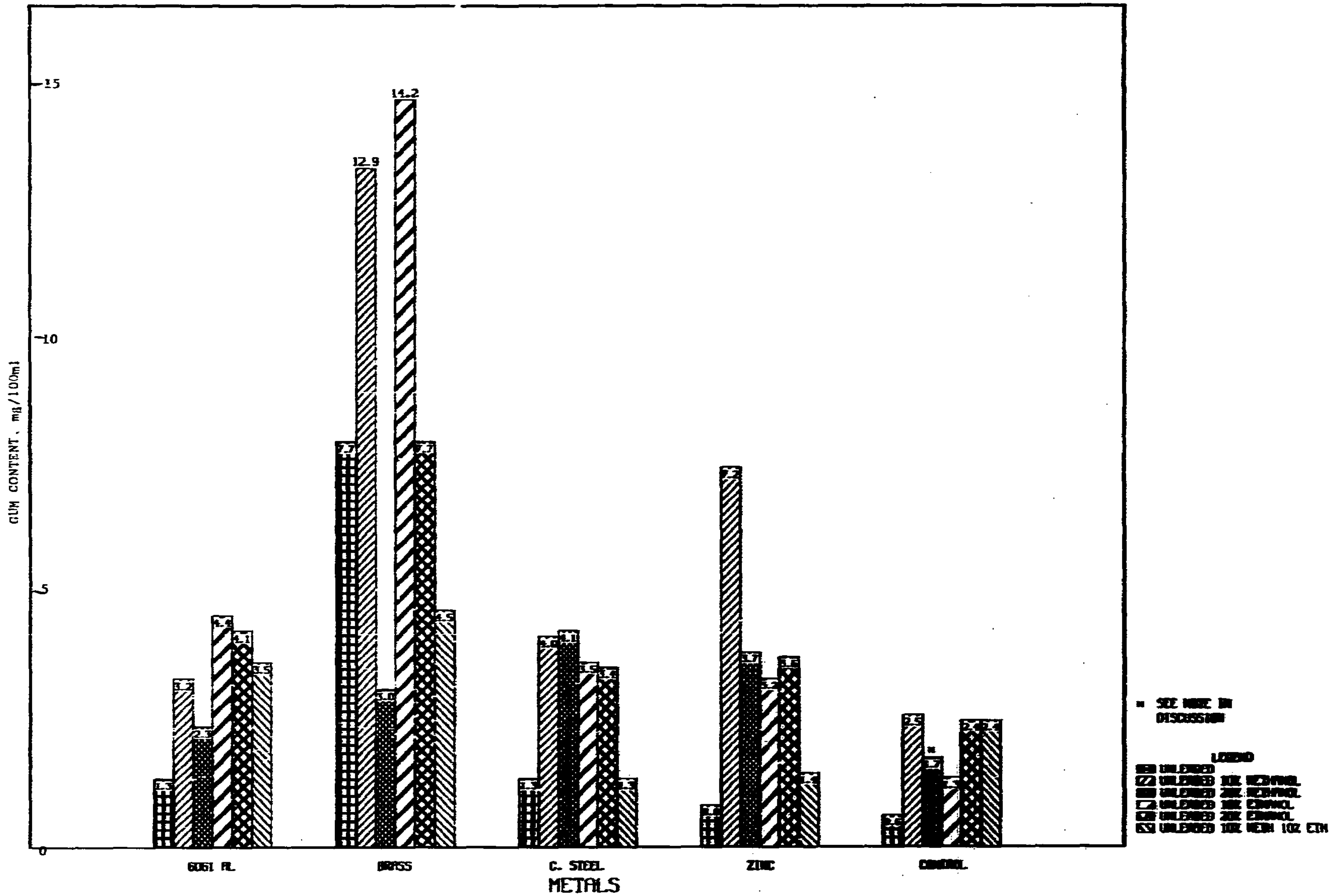

Figure 56. Washed gum content of test fuels conditioned with metals.

c. **Distillation.** Distillation tests were performed on the samples to determine boiling point ranges and residue. ASTM Method D-86 was employed, utilizing a Precision Scientific automatic distillation apparatus. Complete temperature/volume recovery curves were recorded. Data points—from initial boiling point to end point, including losses and residue—were tabulated.

An attempt was made to correlate the distillation ranges of the fuels with the various test materials. An evaluation of the data to ascertain deleterious effects was inconclusive. The percent residue distillation data were tabulated and reviewed in an effort to correlate general trends of material incompatibility with the test fuels. Again, the analysis was inconclusive. It was evident that, although determination of temperature/volume recovery curves has relevance for fuel characterization, the data derived are not applicable to a material/fuel compatibility study. Distillation data are given in Tables 28 through 32.

d. **Reid Vapor Pressure.** Reid Vapor Pressure tests were performed on material samples to ascertain changes in volatility. The testing procedure as outlined in ASTM Method D323, Paragraph 6.4, and Modification Paragraph 6.2—cooling of an air chamber in a refrigerator at 4°C—was employed.

The lids used on the containers for the materials compatibility study did not provide airtight seals in all cases, consequently a random loss in volatility could arise. The preparation of fuel/alcohol blends for each 5-gal batch process also contributed to small losses in fuel volatility. A review of this test data when referenced to the control samples could not pinpoint small incremental changes with sufficient reliability. It was further evidenced that precise relationships of RVP with reference to materials could not be established from this study. However, the results are tabulated in Tables 25 through 27.

IV. CONCLUSIONS

9. Phase I.

a. Generally, fuel/alchohol blends have a greater degradative effect on the physical properties and serviceability potential of typical fuel-resistant elastomers than do unleaded or leaded gasolines, methanol or ethanol, individually.

b. Urethane elastomers should not be used for applications involving contact with alcohol or fuel/alcohol blends.

c. Methanol, either singly or as a component of a gasohol, effects greater deterioration of elastomers than does ethanol.

d. Methanol and ethanol, as constituents of fuel blends, cause the most pronounced acceleration of elastomer deterioration when at the 10 percent to 20 percent concentration level. Increased alcohol content produces proportionately lesser enhancement of swelling and tensile strength loss.

e. Elastomers, such as the fluorocarbons, fluorosilicones, polysulfides and NBR/PVC blends display the best resistance to the deleterious effects of reference fuels and leaded and unleaded gasolines. Substitution of alcohols in these fuels imparts a slightly greater deterioration of tensile strength and increased swelling, but not to a sufficient degree that would disqualify these materials for military usage.

f. The moderate fuel resistance of polychloroprene compounds is not adversely affected by substitution of alcohols in gasolines or reference fuels.

g. ECO and NBR compounds, also moderately fuel resistant, display slight to significant deterioration of properties when exposed to fuel/alcohol blends. Endorsement for use where gasohol is involved should be monitored closely.

h. PNT and CSM compounds inherently poorer in fuel and gasoline resistance should not be endorsed for use in gasohol blends.

i. Fluorocarbon, fluorosilicone, polysulfide, and CSM compounds display adequate resistance to both diesel fuel and diesel/alcohol blends.

j. NBR and polyurethane compounds display significant increased property degradation upon exposure to diesel/alcohol blends.

k. Acceptability for use in diesel/alcohol blends of ECO, NBR/PVC, NBR/CPE, and chloroprene is marginal and contigent upon evaluation of all performance factors.

10. Phase II.

a. The addition of alcohols to fuels has various effects on commonly used plastics in fuel systems. Due to the hygroscopic nature of methanol, plastics such as nylon 6/6 and nylon 6/6 glass-filled must be avoided. The plasticization effects on polypropylene by most fuel mixtures with subsequent swell and loss of strength make it a poor choice for several components in these systems.

b. More tests are necessary to obtain conclusive results regarding compatibility of PBT and phenolic resin with the various fuels used in this investigation.

c. The corrosive action of alcohol blends on metallic materials could not be established within the scope of this study. Longer immersion periods at a higher temperature would be required to effect discernible visual changes on the surface of the metals studied.

d. Coating of metals with a resinous plastic material is known to aid in the prevention of corrosion. When alcohol, especially methanol, is mixed with gasoline, its inherent deleterious effect along with its moisture content tend to nullify the intended corrosion prevention mechanism of the coating.

11. Phase III.

a. The use of specific gravity measurements as a tool to determine fuel/elastomer compatibility is limited. Changes are usually minimal. However, extreme fuel effects, such as leaching of plasticizer and/or replacement with fuels can be isolated with the assistance of such information.

b. Plastics and metals effect even less significant changes in fuel specific gravity, and any increases or decreases noted cannot be correlated with ultimate performance.

c. Washed and unwashed gum determinations effectively delineate and substantiate elastomer/fuel compatibilities as derived from physical testing and volume swell measurements. The superiority of the fluorocarbon and fluorosilicone elastomers and the preference for polyether over polyester urethanes, particularly where contact with fuel/alcohol blends is involved, is evident. However, the ultimate significance of gum content is contingent upon specific end-item applications; i.e., the extent of fuel-elastomer contact.

d. Polypropylene, nylon 6/12, and phenolic plastics contribute the highest washed and unwashed gum content to fuels. However, actual values, when compared to those for rubber, are lower. The extent of plastic/fuel contact of such end items is minimal. Thus, few isolated cases of contamination would be encountered.

e. Certain metals such as brass and zinc can induce higher then normal washed and unwashed gum content in fuel/alcohol blends. Carbon steel and aluminum effects were not deemed significant.

f. Reid vapor pressure and distillation data do not provide discriminating criteria from which fuel/material compatibilities can be derived.

g. All of the fuels tested except for those exposed to fluorosilicone, Viton VTR-10, ether urethane, J-232 Polysulfide, 11ECO-1, and the Nitrile-PVC M-908 tank coating exhibited satisfactory oxidation stability performance.

h. The fuels did not display any corrosive characteristics after exposure to the test materials.

APPENDIX A

COMPOUNDING INGREDIENTS AND SUPPLIERS LIST

1-Agerite Resin D	Polymerised 1,2-dihydro-2, 2, 4 Trimethyl-Quinoline Antioxidant	R. T. Vanderbilt
2-Agerite Stalite S	Mixture of Octylated Diphenylamines, Antioxidant	R. T. Vanderbilt
3-Diak No. 7	Triallylisocyanurate	E. I. DuPont
4-Elastomag	Magnesium Oxide	Morton Chem.
5-ERD-90	Red Lead Dispersion	Wyrough & Loser
6-Hycar 1031	Acrylonitrile Butadiene Copolymer, Nitrile, (NBR) Rubber having high Acrylonitrile content	Goodrich Chem.
7-Hydrin 200	Epichlorohydrin Ethylene Oxide Polymer, ECO Rubber	Goodrich Chem.
8-Hypalon 48	Chlorosulfonated Polyethylene Rubber containing 43% Chlorine.	Dupont
9-Kenrich BLE	75% active powder of the reaction product of Diphenylamine and Acetone	Kenrich
10-Litharge	Lead Monoxide	Eagle-Picher
11-Luperco lo1XL	2,5-Dimethyl - 2,5-Bis (t-Butylperoxy) Hexane, Organic Peroxide	Lucidol Div of Pennwalt
12-Luperco CST	2,4-Dichlorobenzoyl Peroxide in Silicone oil	Pennwalt
13-Maglite D	Magnesium Oxide, high activity	Merck & Co
14-MBTS	2,2′ Di-Benzothiazyl Disulfide	Uniroyal
15-Methyl Tuads	Tetramethylthiuram Disulfide	R. T. Vanderbilt
16-NBC	Nickel Dibutyldithiocarbamate	DuPont
17-Neoprene WRT	Polychloroprene Rubber with Crystallization resistance	DuPont

18-Paracril 18-80	Acrylonitrile Butadiene Copolymer, Nitrile Rubber (NBR), having low Acrylonitrile content	Uniroyal
19-PNF-200	Fluorophosphasene Rubber	Firestone
20-Santocure	N-t-Butyl-2-Benzo-Thiazolesulfenamide	Monsanto
21-Silastic LS-53	Fluorosilicone Rubber	Dow Corning
22-Tetrone A	Dipentamethylene Thiuram Hexasulfide	DuPont
23-Thiokol ST	Polysulfide Rubber	Thikol Chem.
24-TP-95	Di(Butoxy-Ethoxy-Ethyl) Adipate Plasticizer	Thikol Chem.
25-Viton B-910	Fluorocarbon Elastomer, Viton B Rubber containing Accelerator and Curative	DuPont
26-Viton VT-R-4590	Improved fluids-resistant Fluorocarbon Elastomer	Dupont
27-Vulcup 40 KE	2-2' -Bis (t-Butyl Peroxy) Diisopropylbenzene on Burgess KE clay	Hercules
28-Warecure C	Ethylene Thiorurea active ingredient coated with oil	Ware Chem.

APPENDIX B

ANALYSIS OF AROMATIC CONTENT OF LEADED AND UNLEADED GASOLINES

Sample No.	Type	Aromatics	Olefins	Saturates
10	Leaded	29.7	3.3	67.0
11	Unleaded	32.8	2.8	64.4
11A	Unleaded	36.8	2.3	59.1

Method: ASTM D1319

Performed by: US Army Fuels & Lubricants Research Laboratories
Southwest Research Institute
San Antonio, Texas

APPENDIX C

CONVERSION TABLE

U.S.	TO	SI
1 lb/in.^{2}	=	6.894757 kPA
ounce (fluid)	=	29.5735 cm^3
sq. in. (in.^{2})	=	6.4516 cm^2
lb (avoir)	=	0.4536 kg
°C	=	5/9 (°F - 32)

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